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CHARACTERIZATION OF VERTICAL IMPACT DEVICE ACCELERATION PULSES USING PARAMETRIC ASSESSMENT: PHASE II ACCELERATED FREE-FALL

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Interim Report

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14. ABSTRACT Phase II of a research effort using the Vertical Impact Device (VID) located in Bldg 824, Wright Patterson AFB OH., was conducted to continue research of the facility's performance capabilities. The data analysis from Phase I indicated that the impact pulses had velocity changes that were below newly defined WIAMan program requirements, and a modification to the VID would need to be fabricated to generate velocity changes in excess of 32 ft/s (10 m/s). Phase II of the research focused on the design and assessment of the Accelerated Freefall Device (AFD) to increase the velocity change currently generated by the VID facility in order to meet the new program velocity change requirement. The AFD was composed of a bungee cord system interfaced between the VID free-fall carriage and the reaction mass to provide an initial velocity at carriage release. The approach was to conduct tests on the VID with the AFD installed using various energy attenuators, and then compare the acceleration and velocity change data to similar test conditions from the Phase I (no AFD) data set. The first series of tests with the AFD installed on the VID were conducted using the red urethane (Red IMPAC) programmers on the drop carriage, and showed that the AFD progressively increased the peak acceleration and the velocity change with increasing drop height by 89% and 55% respectively at the maximum drop height tested (50 inches). The generated prediction curve for velocity change indicated a velocity change of approximately 37.5 ft/s (11.4 m/s) at the currently estimated maximum drop height of 80 inches on the VID. The second series of tests were conducted using felt programmers positioned on top of the reaction mass. All felt tests were conducted with 20S1 felt density with thickness of either 0.5 or 1.0 inch. The AFD progressively increased the peak acceleration and the velocity change with increasing drop height for both felt thickness configurations. A maximum velocity change with AFD at 80 inch drop height was found to be 39 ft/s (11.9 m/s). The third and final test series evaluated an additional requirement from the WIAMan program to determine whether the VID facility could produce velocity changes above 25 ft/s (7.6 m/s) with time-to-peak (TTP) values between 5 and 10 ms or greater. The time-to-peak velocity increased about a 3 ms, from approximately 3.5 ms to between 6.5 and 7.0 ms, as a function of using two layers of felt. The AFD can meet the new WIAMan program requirements.

15. SUBJECT TERMS Vertical impact, High-G impact, urethane programmer, felt programmer, accelerated free-fall, WIAMan, IMPAC 3636 machine

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1.0 OVERVIEW

The Aircrew Biodynamics and Protection (ABP) Team of AFRL (711 HPW/RHCPT) and their in-house technical support contractor, Infoscitex, conducted a series of tests to identify the performance capabilities of the Vertical Impact Device (VID). The VID is a Monterey Research Laboratory IMPAC3636 high-G impact test machine with seismic suspension, and is currently situated at the 711 Human Performance Wing (HPW), Airman Systems Directorate in Bldg. 824 at Wright Patterson AFB, OH. The VID impact facility is used to generate short duration, very high amplitude impact acceleration profiles to evaluate the effects on human and manikin subjects, and define the effectiveness of operational and prototype protection concepts, for the purpose of improving warfighter performance. The system can provide a maximum acceleration in excess of 1000 G for very short durations, maximum velocity changes of 50 ft/s (15.24 m/s) and pulse durations from 1 to approximately 30 ms using specialized facility adaptors and configurations beyond the standard free-fall set-up.

The results provided in this report will be used as a reference for future test applications performed within the 711 HPW, as a benchmark for post-refurbishment and post-maintenance performance verification, and to potentially determine the degree of participation in the Army's Warrior Injury Assessment Manikin (WIAMan) development program. This test series was the second of several phases and focused on the characterization of a specially designed Accelerated Free-Fall Device (AFD). The AFD was integrated onto the VID to increase the impact energy and provide greater velocity changes to meet changing program requirements.

2.0 BACKGROUND

One of the signature wounds being identified with the war in the Middle East, as more and more wounded soldiers return home, is blast injuries. Blast injuries are caused by being in proximity to an explosive device when it detonates, and which have been seen previously but have been more closely documented on the battlefield since World War I (WWI). Improvements in body armor and better battlefield medicine is allowing more wounded soldiers to live and return home after suffering a blast injury. Military surgeons are being trained to better understand the pathology of blast injuries and spot the more subtle symptoms in patients enduring treatment. In the war in Iraq, Improvised Explosive Devices or better known as IEDs are the weapon of choice for insurgents and widely used against our soldiers. The IEDs can cause blast injuries that have the ability to cause compounded catastrophic injuries, as well as the less visually observed or hidden injuries related to brain trauma as a result of a blast wave. As a result, the Army initiated the WIAMan program.

The WIAMan program has the main objective to gain an understanding of the biomechanics of injuries that occur in a combat vehicle underbody blast event involving a landmine or improvised explosive device. This will be accomplished using the data generated during this program to fabricate a specialized manikin that will be used in military Live-Fire Test and Evaluation efforts for the development of injury criteria. The new injury criteria and the new manikin will then be used to develop and evaluate mitigation technologies for ground combat vehicle seating systems. Part of the approach for the WIAMan program will be to define the loading environment which produces the injuries being investigated. The defined loading environment will then be used to measure the applied loads and resultant injuries to test specimens and produce tissue properties, human injury tolerance and response corridors, and ultimately injury risk curve. This requirement to understand the blast loading environment led to the initiation of the 711 HPW program to evaluate the impact pulse characteristics of the VID facility.

Previous research on the VID (Knox, T., Pellettiere, J., Perry, C., Plaga, J., Bonfeld, J., 2008; Veridian Contract Report, CDRL A005, 2002; and Salerno, Capt. M.D., Brinkley, J.W., Orzech, Capt. M.A., 1985) focused on application of an energy pulse to either a piece of equipment or a human subject to determine its biodynamic response. The energy pulse was defined by achievement of a maximum peak acceleration value. Very little if any work had been completed to relate the drop height of the VID to a range of acceleration values with a specified time-to-peak (TTP); therefore, the impact characterization research program was initiated.

The first phase of VID testing determined the efficacy of using the facility to support the WIAMan program which had initial impact acceleration pulse requirements of over 300 G with pulse TTP values in the 5 to 10 ms range. The test program approach used a parametric analysis with the objective to define and evaluate the performance effect of various impact attenuators on VID impact acceleration. Over 100 impact tests were completed during Phase I, and consisted of varying the energy attenuators, defined as the high-density (red) urethane programmers and industrial felt of varying density and thickness, while progressively increasing the drop height of the VID's drop table. The concept of using felt was borrowed from the work of Childers (Childers, M.A. 2002). One red urethane programmer, 4 felt densities, and 4 felt thicknesses were evaluated, and were used as the basis to separate the data analysis into three sub-phases.

The measured response was the acceleration recorded on the VID drop carriage, and the calculated velocity change and TTP velocity change. The data analysis from Phase I indicated that the impact pulses could meet the original 300 G requirement, but had velocity changes that were below the recently defined WIAMan program requirements, and a modification to the VID would need to be fabricated to generate velocity changes in excess of 32 ft/s (10 m/s).

A test fixture (the AFD) was therefore designed to increase the velocity change currently generated by the VID facility in order to meet the additional WIAMan program requirement. The AFD interfaced a bungee cord system between the VID free-fall carriage and the reaction mass, which provided an initial velocity to the carriage at the moment it was released into free-fall. This initial velocity would provide for greater impact energy providing higher impact G-levels and velocity changes. The main objective of Phase II of the VID testing was to evaluate the efficiency of the AFD to generate the required WIAMan pulse shape using the VID facility.

3.0 OBJECTIVES

The initial performance requirements for the VID to support the WIAMan program were impact acceleration pulses over 300 G with pulse TTP values in the 5 to 10 ms range. New performance requirements required a velocity of greater than 32 ft/s. The Phase II test program to determine the VID pulse characteristics using the AFD pursued the following objectives:

(1) Evaluate the performance of the VID's high-density (red) urethane programmers as a function of progressively increasing drop heights of the VID drop table with the AFD.

(2) Evaluate the performance of different industrial felt thicknesses samples of the same felt density as a function of progressively increasing drop heights of the VID drop table with the AFD.

4.0 TEST FACILITY AND EQUIPMENT

4.1 Vertical Impact Device

The VID or IMPAC 3636 test machine was manufactured in the 1960's, and was given to the AFRL biodynamics facility from NASA. The VID is a high acceleration, shock testing machine capable of providing a maximum acceleration of 1000 G. It is capable of providing a maximum velocity change of 50 ft/s (15.24 m/s) and minimum pulse duration of 1.6 milliseconds depending on the selected impact programmer. The maximum drop height is between 8 to 12 feet depending on the mounted test fixture. A test is performed by dropping the carriage supporting the test fixture onto a reaction mass.

The major components of this facility consist of the carriage, reaction mass, elastic impact programmers, lifting and braking system, and control console. The carriage is a single piece high-strength aluminum (7079-T6) forging with machined surfaces carefully designed to provide a uniform load distribution, and weighing 1300 lbs. Bronze bearings guide the carriage on two hard chrome-plated rails. The reaction mass is a 12,000-lb forged steel block mounted on a critically damped, constant force, nitrogen and oil suspension system.

Impact programmers are used to control the shape, peak acceleration, and duration of the shock pulse. The programmers are mounted on the underside of the carriage or on the top of the reaction mass, and control the contact surface between the carriage and the reaction mass. Programmers can be combined in various configurations to provide specialized shock pulses. The carriage lifting system consists of a cable, pulley, and lifting tube driven by one hydraulic cylinder, for each of the two side supports. Pneumatic friction brakes in the carriage assembly clamp the carriage to the guide rails when the desired drop test height has been reached; the lifting tubes are then lowered to their pre-test position at the bottom of the rails. The carriage is released at test initiation by a fast-acting valve in the brake system. The brakes are again energized to stop any rebound of the carriage after the carriage impacts on the reaction mass. The control console contains all the switches and condition lights for the remote control of the facility. The console also houses the hydraulic power for the lifting system. The VID is shown in Figure 1.

The positive axis of the coordinate system for the test configuration for this program is defined with respect to the top of the carriage, or with respect to the orientation of a manikin positioned in the seat mounted to the VID carriage. The coordinate system is shown for this test configuration in Figure 1. In order to obtain a shock pulse of desired maximum acceleration and duration and to prevent damage to the shock test machine, it was necessary to place a programmer (shock-mitigating material) between the shock table and reaction base. This material has energy-absorbing characteristics, and typical programmers are constructed from felt or urethane materials. A third type of programmer, the universal programmer, uses pressurized air and is applicable for low accelerations.

Figure 1. 711th HPW Vertical Impact Device

4.2 VID Configuration with Accelerated Free-Fall Device

The primary modification to the VID for this Phase II test series was the installation of the AFD. The AFD consisted of several components and included right and left tower bars, right and left bungee cord guide tracks, and right and left pulley anchors, and the bungee cord used to provide an initial potential energy into the VID drop carriage.

The AFD tower bars were fabricated fixtures composed of steel box beams and attachment plates designed to provide termination points for the bungee cord system on the front and back side of the VID structure. The tower bars are shown in Figure 2, and the termination of the bungee cord system is shown in Figure 3.

The AFD bungee cord guide tracks were fabricated aluminum alloy fixtures designed to route the bungee cords from the front to the back of the VID drop carriage. Two units were fabricated for the right and left side of the VID carriage. A side view of the bungee cord guide track is shown in Figure 4. A front and top view of the VID carriage showing the mounting configuration of the bungee cord guide tracks is shown in Figure 5.

The AFD pulley anchors were fabricated aluminum alloy fixtures designed to provide a fixed point on the reaction mass (two on each side of the mass, one in the front and one in the back) for the bungee cords to travel around. The pulley anchors provided the fixed point for the bungee

cords to stretch as the VID carriage was raised upwards relative to the reaction mass (which is stationary). A pulley anchor mounted on the front right corner of the reaction mass is shown in Figure 6. The figure shows how the bungee cords come down from the tower bar, wrap under the pulley anchor, and then proceed up to the AFD guide track on the right side of the VID test fixture.

The bungee cord was purchased from Superior Bungee Corporation. Four separate cables were purchased, and each cable was 37 foot long with a ¾ in. diameter cable, and was supplied with a steel reinforced loop at each end. Two cables were used on each side of the VID, and the loops terminated into load cells positioned at both the front and back of the AFD tower bars. This is shown in Figure 3.

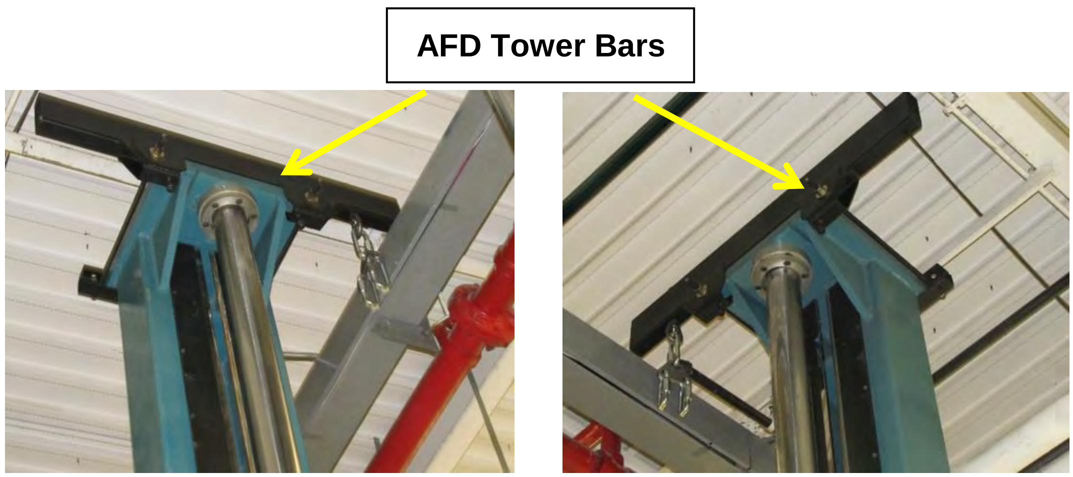

Figure 2. Left and Right AFD Tower Bars at Top of VID Rail Towers

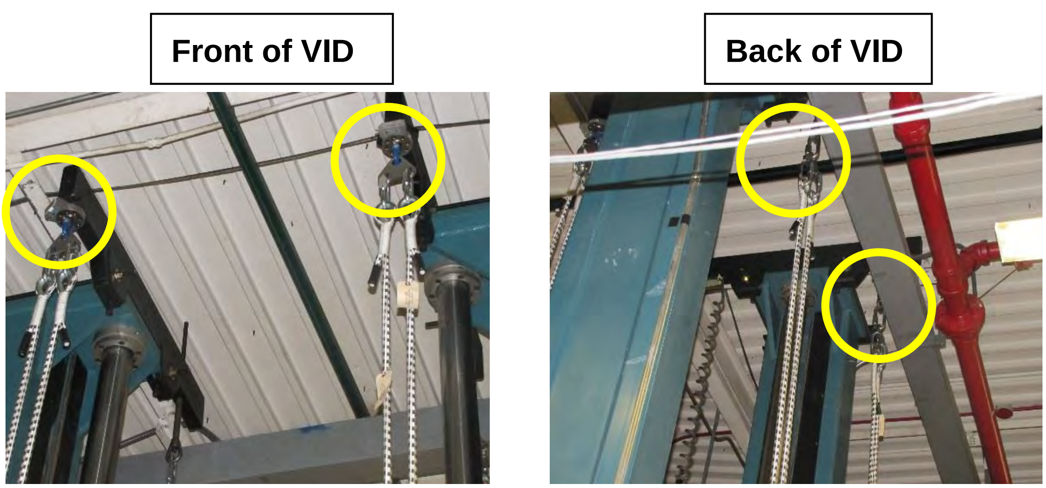

Figure 3. Right/Left Bungee Cord Termination Points on Front/Back of AFD Tower Bars

Figure 4. Side View of AFD Bungee Cord Guide Track

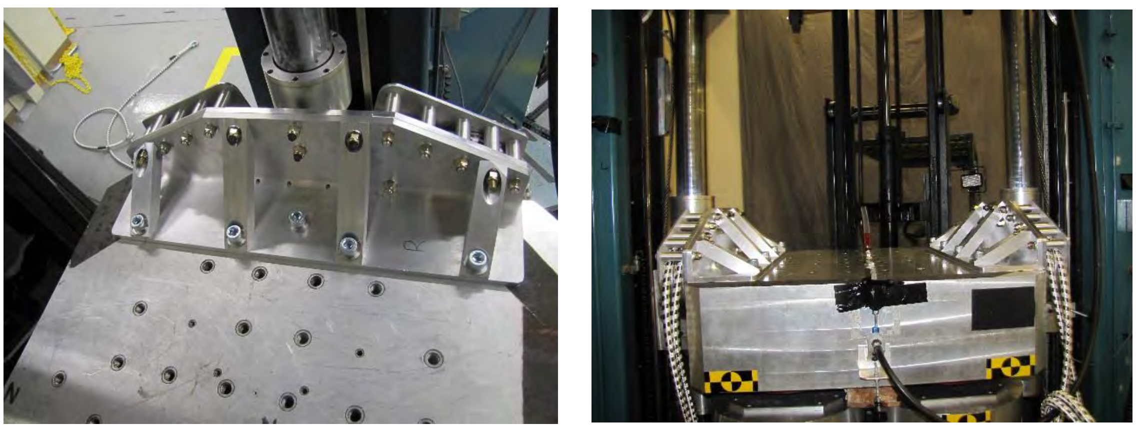

Figure 5. Top and Front View of VID Carriage Showing Location of AFD Guide Track

Figure 6. Installation of AFD Pulley Guide on VID Reaction Mass

The assessment of the AFD was accomplished by conducting a limited number of tests that repeated test conditions from the previous parametric evaluation of impact energy attenuators in Phase I. The Phase I parametric evaluation was conducted using four red VID programmers mounted in a four-square grid pattern on the bottom of the drop table. Additional programmer configurations were also evaluated using different combinations of felt sample thickness and density that were positioned in a four square grid pattern on the top of the reaction masses' 1 ft^2 steel plates. The reaction mass's suspension system was pressurized to 2000 psi. as directed by the IMPAC 3636 instruction manual.

4.3 Red IMPAC and Felt Programmers

The circular red urethane programmers, each mounted to a 1 ft^2, 0.25 in. thick steel plate, had an approximate diameter of 11.75 in., and an edge thickness of 0.5 inch. The programmer increased in thickness towards the center where it became a flat topped cone with an approximate diameter of 2.0 in. and a thickness of 0.94 in. at the center.

The felt samples were purchased from the Bacon Felt Company in Rochester, NH, and consisted of 1 sq. ft. samples that varied in density and thickness. The densities available covered the range from 16 to 32 lbs as defined by Bacon Felt for a 3 x 3 ft. square sample that is 1.0 inch thick (the first two numbers of the felt's ID# indicate the density of the material… 16S1, 20S1, 26S1, and 32S1). The sample thicknesses available varied from 0.25 in. up to 2.0 in. The tests of the effects of felt thickness were conducted with a felt sample that had a felt density of 20 lbs (Felt ID# 20S1).

5.0 INSTRUMENTATION AND DATA COLLECTION

Transducers were chosen to provide the optimum resolution over the expected test acceleration ranges. Full-scale data ranges were selected to provide the expected full-scale range plus 50% to assure the capture of peak signals. All transducer bridges were balanced for optimum output prior to the start of the program. The appropriate accelerometers were adjusted with software for the effect of gravity by adding the component of a 1 G vector in-line with the force of gravity along the accelerometer axis.

The coordinate system (shown in Figure 1) used was the Right-Hand Rule with the z-axis parallel to the VID guide rails, and with positive being up towards the top of the VID facility. The x-axis is perpendicular to the z-axis and points outward away from the VID impact table. The y-axis is perpendicular to the x- and z-axes according to the right-hand rule. The linear accelerometers were wired to provide a positive output voltage when the acceleration experienced by the accelerometer was applied in the +x, +y and +z directions.

5.1 Facility Instrumentation

Acceleration measurements were taken on the VID at three different reference point locations on the top surface of the carriage or drop table (shown in Figure 7). One reference point was located at the geometric center of the table, and the second and third at points close to the tables two guide rails (within 2 inches from outer curvature of either rail). The accelerometer package was a tri-axial array consisting of three linear accelerometers mounted in each of the three coordinate axes.

The tri-axial accelerometer package mounted at the geometric center of the table was composed of two Entran Model 7264C-500 accelerometers mounted in the x and y-axis, and a single MEAS EGCS-1000-S425 accelerometer mounted in the z-axis. The tri-axial accelerometer packages mounted at the points on the table, close to the table's guide rails, were composed of two Entran Model 7264C-500 accelerometers mounted in the x and y-axis, and a single MEAS EGCS-1000-S425 accelerometer mounted in the z-axis.

Figure 7. Location of Three Tri-axial Accelerometer Arrays on Top of VID Table

5.2 Transducer Calibration

On-site personnel from Infoscitex, Inc conducted pre- and post-calibrations on all sensors used on the carriage and seat fixture. Calibration records of individual transducers as well as the Standard Practice Instructions are maintained in the biodynamic facility's Impact Information Center. For this test program, a record was made identifying the data channel, transducer manufacturer, model number, serial number, date and sensitivity of pre-calibration, date and sensitivity of post-calibration, and percentage change. Pre- and post-calibration information is maintained with the program data. The instrumentation used in this study is listed in the Electronic Instrumentation Data Sheet (See Appendix A).

5.3 Data Acquisition Control

The data collection process was controlled by a technician seated at the VID's Master Station Control located on the side of the VID facility. A test was initiated when the technician initiated a verbal countdown. The technician then initiated the data collection and the video collection with separate hand-held switches at t = -2 sec. Software was used to establish a zero reference for all transducers prior to table impact.

5.4 Data Acquisition System

Transducer excitation, signal amplification, filtering, digitizing, and transmission was provided off-board the VID carriage by a computer-controlled data acquisition system (DAS). This research program used the TDAS G5 DAS manufactured by Diversified Technical Systems

(DTS), Inc., to collect all the fixture data for each test as defined by the test matrix. The 32-channel TDAS G5 was mounted off-board the VID next to the Master Station Control laptop. The TDAS G5 is a ruggedized, DC powered, fully programmable signal conditioning and recording systems for transducers and events. The TDAS G5 was designed to withstand a 100 G shock.

The signal conditioning accepts a variety of transducers including full and partial bridges, voltage, and piezo-resistive sensors. Transducer signals are amplified, filtered, digitized and recorded in onboard solid-state memory. The data acquisition system is controlled through an Ethernet interface using the Ethernet instruction language. A laptop PC with an Ethernet board configures the TDAS G5 before testing and retrieves the data after each test. For this program, the DAS collected data at a 20K sample rate with a 2 KHz anti-aliasing filter.

5.5 Quick Look Data Plots

After each test, the filtered data were graphically plotted in a portrait format of 4-6 plots per page, and grouped with similar channels. The spreadsheet of plots also contained pertinent maxima, minima, and respective times of each occurrence. For all data, time = 0 was at initial carriage motion. The plots arranged in this fashion included: displacement versus time, force (load) versus time, and acceleration versus time.

5.6 High Speed Video and Photography

Two Phantom Miro-3 High-Speed digital cameras (Figure 8) were used to collect video of each test. The cameras were mounted off-board the VID facility at perpendicular and oblique angles relative to the front of the facility.

The Phantom Micro line is a compact, light-weight, rugged family of cameras targeted at industrial applications ranging from biometric research to automotive crash testing. Rated to survive 100 G acceleration, this rugged camera can take 512 x 512 images at up to 2200 frames-per-second (fps). Reduce the resolution to 32 x 32 and achieve frame rates greater than 95,000 fps. With an ISO rating of 4800 (monochrome, saturation-based ISO 12232), the camera has the light sensitivity for the most demanding applications. With shutter speeds as low as 2 microseconds, the user can freeze objects in motion, eliminate blur, and bring out the image detail needed for successful motion analysis. The camera accepts any standard 1" C-mount lens. The Phantom Miro-3 member of the family is optimized for applications such as Hydraulically Controlled, Gas Energized (HYGE) crash simulations used in the automotive industry. Selectable 8-, 10- or 12-bit pixel depth allows the user to choose the dynamic range that best meets the demands of the application. The Miro-3 has a number of external control signals allowing for external triggering, camera synchronization, and time-stamping. The camera has both dynamic RAM and internal flash memory for non-volatile storage. Internal battery power allows the camera to be used in an un-tethered mode and ensures data survivability in case of loss of power.

The images for this study were collected at 1000 frames per second (fps). The video files were downloaded and converted to AVI format, and stored in the RH Collaborative Biomechanics Data Bank. Photographs were taken of the test set-up prior to each test. Photographic and video data were stored on an internal network for downloads as requested.

Figure 8. Phantom Miro-3 High-Speed Digital Camera

6.0 EXPERIMENTAL DESIGN

Specially designed test matrices were developed to address the program objectives assessing the efficacy of using a bungee cord system to provide greater velocity change at impact on the VID. Tests were conducted at different drop heights and with either the VID's red urethane programmers, or various combinations of high-density felt thickness and density. The tests were duplications of select test conditions from Phase I of the facility characterization effort without the AFD installed on the VID.

6.1 Red IMPAC Programmer Characterization

The parametric evaluation of the red urethane used four programmers mounted in a four-square grid pattern on the bottom of the drop table. The red programmers each impacted a flat, 1 square foot, 0.25 in. thick, steel plate mounted to the top of the reaction mass as shown in Figure 9. The test matrix for this test series is shown in Table 1.

Figure 9. VID Facility with Installation of AFD and Red VID Programmers

Table 1. Test Matrix for AFD Evaluation with Red IMPAC Programmer

Test Cell	Drop Height (in)	Programmer
A	20	Red Disk
B	30	Red Disk
C	40	Red Disk
D	50	Red Disk

6.2 Felt Programmer Characterization

The AFC evaluation of the felt samples also had the felt positioned in a four-square grid pattern, but on the top of the impact table. As indicated previously, the felt samples consisted of 1 ft^2 samples that varied in density and thickness. The density for this test series remained constant using the felt ID 20S1(density based on 1.0 inch thick, square sample that was 3x3 ft., and this density is indicated by the first two numbers of the sample ID). The sample thicknesses for this test series were either 0.5 or 1.0 inch thick.

Additional testing during this phase also included the introduction of a new impact material configuration. The configuration consisted of two samples of 1 inch felt with a metal plate inserted in between and separating the two samples (felt/plate/felt configuration).

The AFD evaluation was conducted per the test matrices shown in Table 2. The facility set-ups are shown in Figures 10 and 11.

Table 2. Test Matrix for AFD Evaluation with Felt Programmer

Test Cell	Drop Height (in)	Programmer	Felt Thickness (in)
E	20	20S1 Felt	1.0
F	30	20S1 Felt	1.0
G	40	20S1 Felt	1.0
H	50	20S1 Felt	1.0
I	60	20S1 Felt	1.0
J	70	20S1 Felt	1.0
K	80	20S1 Felt	1.0
K1, K2	80	20S1 Felt	1.0
K3, K4	80	20S1 Felt	0.5
O1	20	20S1 Felt	0.5
O2	40	20S1 Felt	0.5
O3,O4,O5	80	20S1 Felt	0.5
O6	80	20S1 Felt	1.0 Felt / Plate / 1.0 Felt

Figure 10. VID Facility with Installation of AFD and Felt Programmers

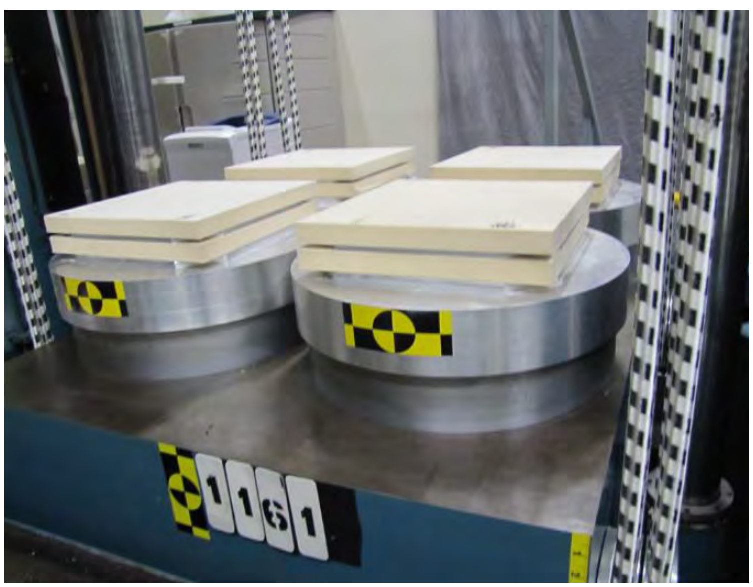

Figure 11. VID Facility with Installation of AFD and Felt/Plate/Felt Configuration

7.0 RESULTS

A total of 54 impact tests were completed on the VID in support of this effort to characterize the acceleration pulses generated by the VID carriage with the installation of a device to increase the velocity change at impact (AFD). This phase of testing consisted of altering the drop height to observe the effects on peak acceleration, velocity change and other variables with the Red IMPAC Programmers in Test 1113 to 1123, and also with the addition of different felt programmers in Tests 1124-1166.

7.1 AFD Assessment with Red Programmer: Test-by-Test Summary

A review of the specific test configuration for each of the red urethane impact tests conducted on the VID is shown with a test-by-test summary documenting test conditions and a brief summary of the key data. The summary is shown in Appendix B.

7.2 AFD Assessment with Red Programmer: Test Data Review

The data collected from testing the red IMPAC programmers is presented in Table 3, and corresponds with the test parameters proposed in Table 1 in the methods section. Both the peak acceleration and the resulting integrated velocity change in ft/s were plotted as a function of progressively increasing drop heights, shown in Figures 12 and 13. Examples of the red programmer data plots generated after each test, via the post-test "quick-looks", is shown in Appendix C.

Table 3. AFD Evaluation with Red IMPAC Programmer: Data Summary Showing Means and Standard Deviations

Test Cell	Drop Ht. (in)	Mean Peak Acceleration (G)	Mean Velocity Change (ft/s)	Mean Velocity Change (m/s)
A	20	336.9 ± 5.8	17.12 ± 0.04	5.22 ± 0.01
B	30	474.5 ± 3.0	21.41 ± 0.06	6.53 ± 0.02
C	40	662.9 ± 2.6	25.27 ± 0.05	7.70 ± 0.02
D	50	832.8	28.65	8.73

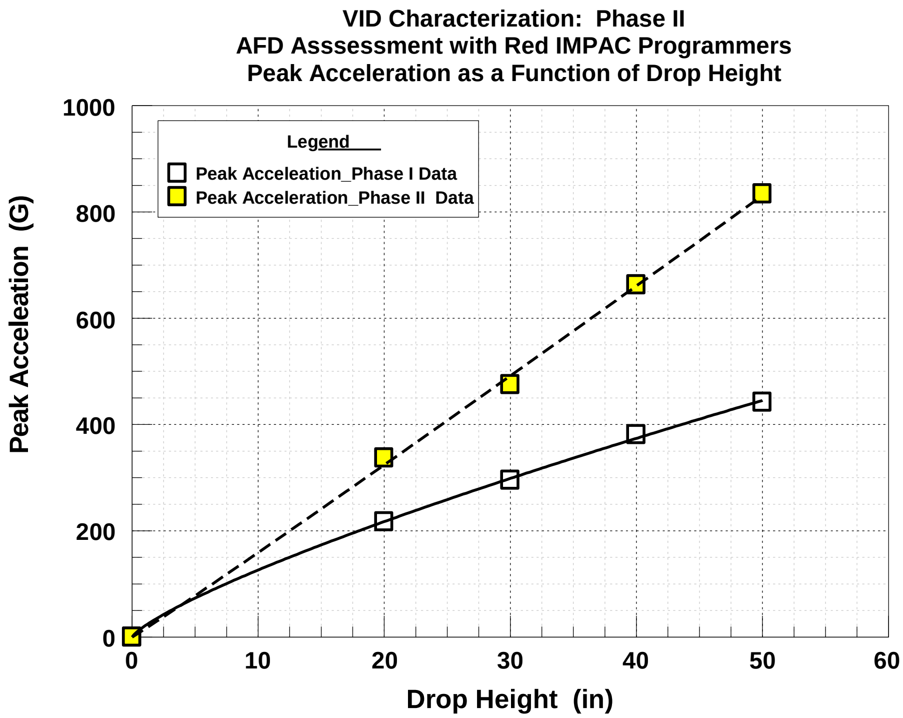

Figure 12. Peak Acceleration as a Function of Drop Height with AFD: Red Programmers

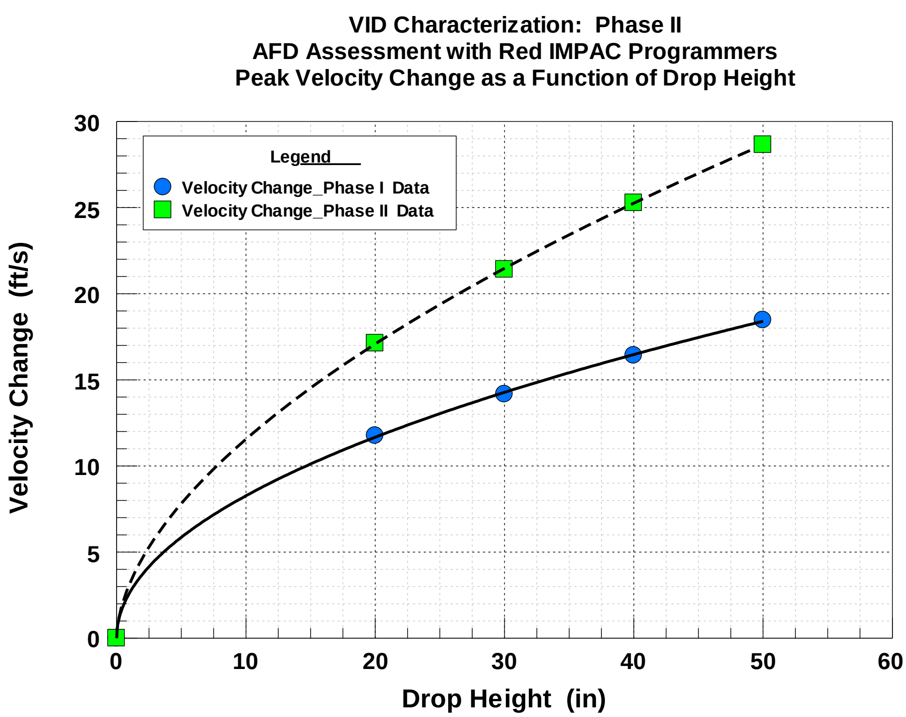

Figure 13. Velocity Change as Function of Drop Height with AFD: Red Programmers

The data used to calculate the statistical means and standard deviations, for the acceleration and calculated velocity change data sets, was composed of data from all the VID tests 1113 through 1123, and used the same accelerometer packages from the Phase I study. Only a single test was conducted at the 50 in drop height due to program time constraints, and due to the very small variation in the data collected at the 20 through 40 inch drop heights. The narrow standard deviation values shown in the data table highlight the repeatability of the VID test facility.

The plots generated from test data showed that a Power Series equation provided the best fit regression line. The Phase II peak mean acceleration (G) as a function of drop height was fit with a Power Series equation defined as $y = 14.91*x^{1.03}$, which provided a Coefficient of Determination (COD) of $r^2 = 0.99$. The Phase II peak velocity change (ft/s) as a function of drop height was fit with a Power Series equation defined as $y = 3.15*x^{0.56}$, which provided a Coefficient of Determination (COD) of $r^2 = 0.99$. Although the plot is not presented, the Phase II peak velocity change (m/s) as a function of drop height was also fit with a Power Series defined as $y = 0.965*x^{0.56}$, which provided a COD of $r^2 = 0.99$. The excellent COD values for all the data sets also highlight the repeatability of the VID test facility, and also provide a tool for estimation of required test parameters.

The regression lines identified in Figures 13 for the velocity response as a function of drop height could be individually plotted to provide prediction curves. The prediction curve could be used to determine the value for maximum velocity change (ft/s) at the current maximum drop height of the VID facility which is approximately 80 inches. The prediction curve from Figure 13 (velocity change in ft/s) is shown in Figures 14, and shows a maximum velocity change of approximately 37.5 ft/s, at a drop height of 80 inches. This is more than a 50% increase over the Phase I value of 23 ft/s at the 80 in drop height (Perry, Burneka, Christopher, Albery, 2016, In Publication).

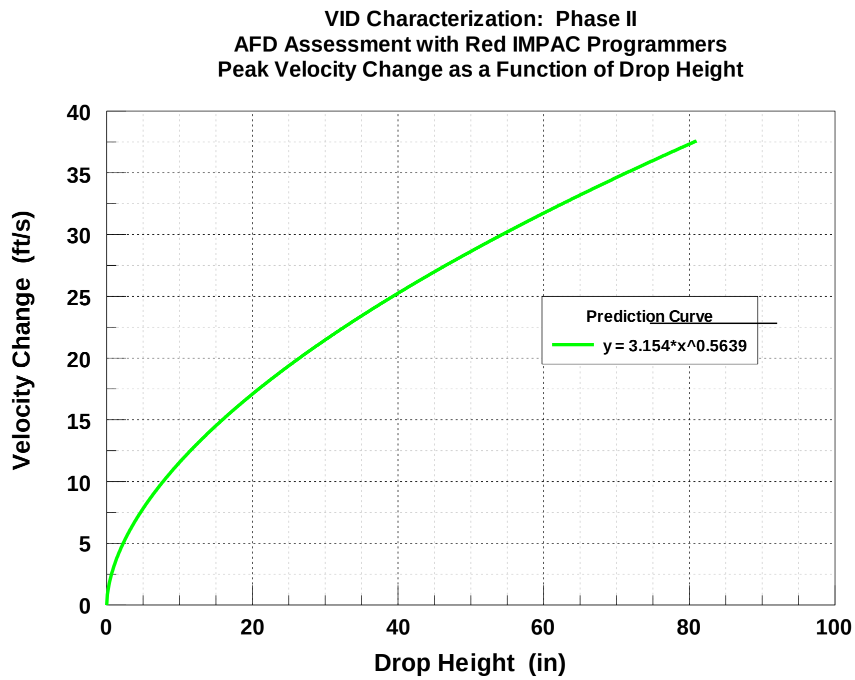

Figure 14. Prediction Curve for Velocity Change with AFD: Red Programmers

One aspect of the test data that Figure 12 and 13 highlights is the variation in response with and with-out the AFD as the drop height increases. This can be shown by calculation of the percent difference of the response due to the installation of the AFD the four drop heights. This allows a further understanding of the effects the AFD on the velocity change.

In order to calculate percent difference between data points collected at the two drop heights with and without the AFD, the percent difference was always referenced to a baseline value, and for this study, the baseline value or $value_b$ was equal to the acceleration or velocity change without the AFD. The following equation was used to calculate the percent difference or Pd the installation of the AFD had on the facility acceleration and velocity change:

$$Pd = \frac{value - value_b}{value_b} \times 100$$

where value is the acceleration or velocity change data collected with the AFD, and $value_b$ is the baseline reference value which is the acceleration or velocity change data value when the AFD was not used (Phase I data set). A positive Pd value indicates that the velocity changed increased with the installation of the AFD. The percent difference calculations are shown in Table 4 and 5.

Table 4. Percent Difference in Peak Acceleration as a Function of the AFD: Red Programmers

Drop Height (in)	Phase I Peak Acceleration (G)	Phase II (AFD) Peak Acceleration (G)	Percent Difference (Pd)
20	217	337	55.3%
30	295	475	65.5%
40	381	663	74.0%
50	442	834	88.7%

Table 5. Percent Difference in Velocity Change as a Function of the AFD: Red Programmers

Drop Height (in)	Phase I Velocity Change (ft/s)	Phase II (AFD) Velocity Change (ft/s)	Percent Difference (Pd)
20	11.76	17.12	45.5%
30	14.17	21.41	51.1%
40	15.83	25.27	53.9%
50	18.47	28.65	55.1%

The percent difference values for the peak acceleration and velocity change data indicate that the AFD had a very noticeable effect on them as the drop height increased while using the Red IMPAC programmer. The percent differences for the peak acceleration data steadily increased as the drop height increased with a maximum percent difference of approximately 90% at the 50 inch drop. Projections of the accelerations using the Power Curves from Figure 12 indicate that the peak acceleration would be doubled at a drop height of approximately 60 inches.

The percent differences for the velocity change data steadily increased at each drop height with the increase exceeding 50% at three of the four drop heights tested. The predicted velocity change value at an 80 inch drop height with and without the AFD indicated a predicted percent increase of 63% with the AFD.

The time history data from two different drop heights were used to plot the generated impact acceleration profiles as a function of time using the red programmers. Two waveforms are from the AFD study (Phase II), and one waveform is from the previous no-AFD study (Phase I). These waveforms also show the variation in pulse width as the drop height increased (Figure 15). The acceleration pulse width can also be used as an estimate of the TTP velocity where the velocity is calculated using the area under the acceleration curve. The plot below shows the TTP velocity changed only about a 1 ms (from 3.5 ms to 2.5 ms) as the drop height was increased for the AFD tests. This is similar to the results from the Phase I study and shows the AFD did not influence the effects of the drop height. The additional waveform from the Phase I study at 50 inches shows how the AFD affected the shape of the acceleration pulse, but also shows that it only slightly influenced the TTP velocity change (No AFD: approximately 3 ms, with AFD: approximately 2.5 ms).

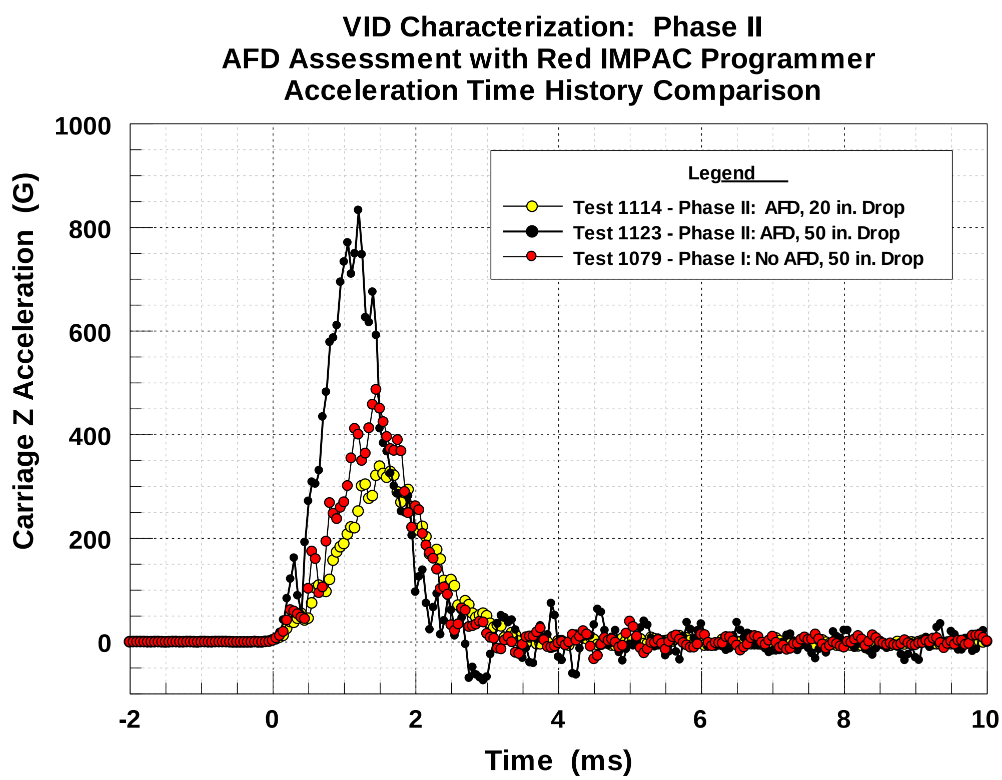

Figure 15. Acceleration Profile at Two Drop Heights – AFD and Red IMPAC Programmer

7.3 AFD Assessment with Felt Programmers: Test-by-Test Summary

A review of the specific test configuration for each of the tests conducted on the VID with different felt programmer configurations is shown with a test-by-test summary documenting the test conditions and a brief summary of the key data. The summary is shown in Appendix D.

7.4 AFD Assessment with Felt Programmers: Test Data Review

The data collected from testing the felt programmers is presented in Table 6, and corresponds with the test parameters proposed in Table 2 in the methods section. The peak acceleration data and the resulting integrated velocity change data in both ft/s and m/s were able to be plotted as a function of progressively increasing drop heights, shown in Figures 16 through 19. Examples of the felt programmer data plots generated after each test, via the post-test "quick-looks", is shown in Appendix E.

Table 6. AFD Evaluation with Felt Programmer: Data Summary Showing Means and Standard Deviations

Test Cell	Drop Height (in)	20S1 Felt Thickness (in)	Mean Peak Acceleration (G)	Mean Velocity Change (ft/s)	Mean Velocity Change (m/s)
E	20	1.0	181.2 ± 4.2	16.9 ± 0.09	5.17 ± 0.02
F	30	1.0	273.2 ± 3.1	21.6 ± 0.08	6.59 ± 0.02
G	40	1.0	351.9 ± 4.8	25.0 ± 0.02	7.62 ± 0.004
H	50	1.0	456.6 ± 7.2	28.2 ± 0.06	8.59 ± 0.02
I	60	1.0	530.1 ± 5.4	30.9 ± 0.12	9.43 ± 0.04
J	70	1.0	646.0 ± 5.3	33.3 ± 0.35	10.16 ± 0.12
K, K1, K2	80	1.0	822.6 ± 36.4	39.0 ± 5.10	11.89 ± 1.55
K3, K4, O3, O4, O5	80	0.5	1389.6 ± 177.3	32.5 ± 5.60	9.90 ± 1.71
O1	20	0.5	274.8 ± 0.8	15.7 ± 0.04	4.79 ± 0.01
O2	40	0.5	624.8 ± 7.2	23.4 ± 0.09	7.13 ± 0.03
O6	80	1.0 Felt / Plate /1.0 Felt	430.1 ± 20.1	35.94 ± 0.43	10.96 ± 0.13

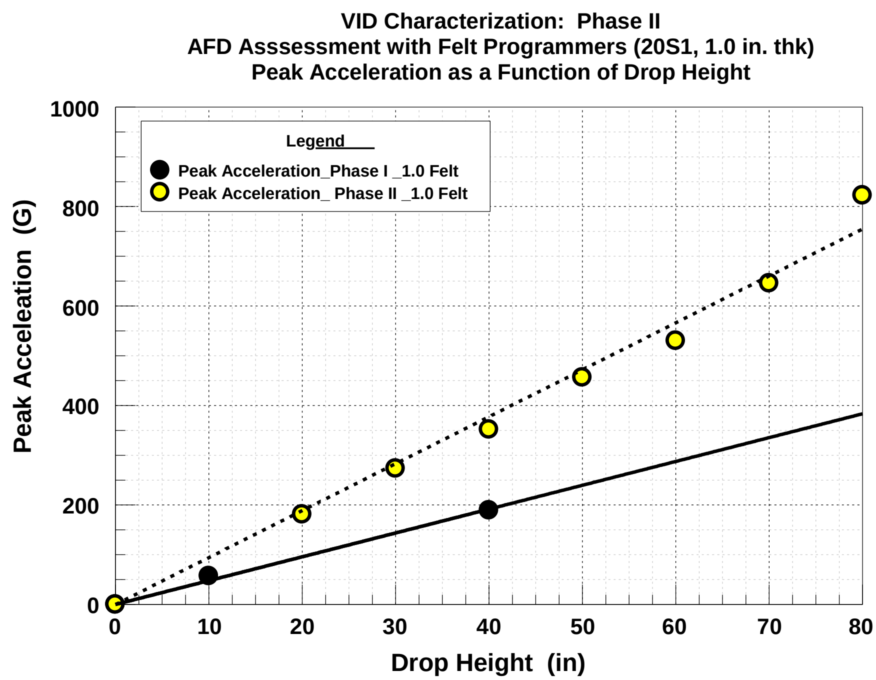

Figure 16. Peak Acceleration as Function of Drop Height w/AFD: 1.0 in. Felt Programmer

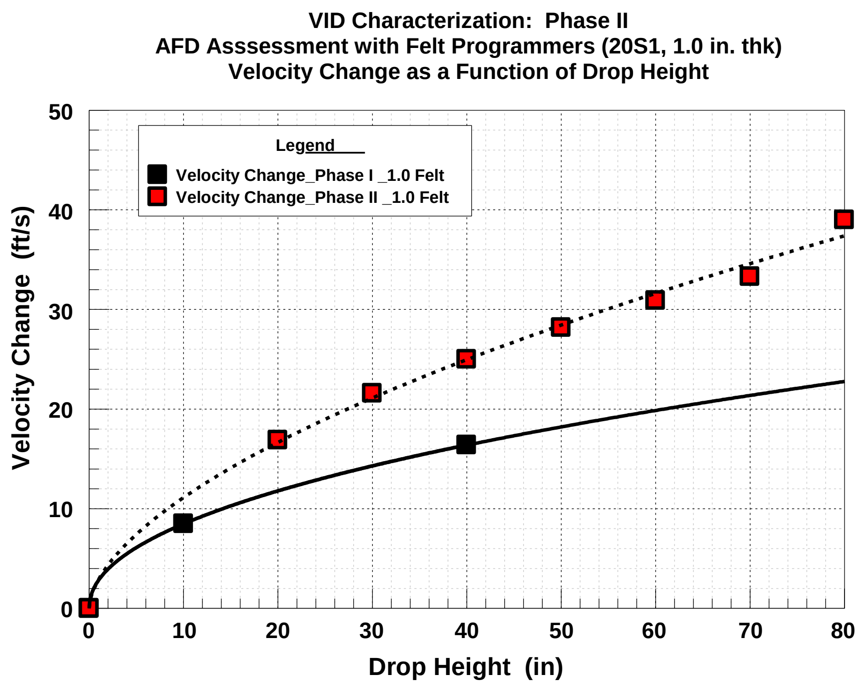

Figure 17. Velocity Change as Function of Drop Height w/AFD: 1.0 in. Felt Programmer

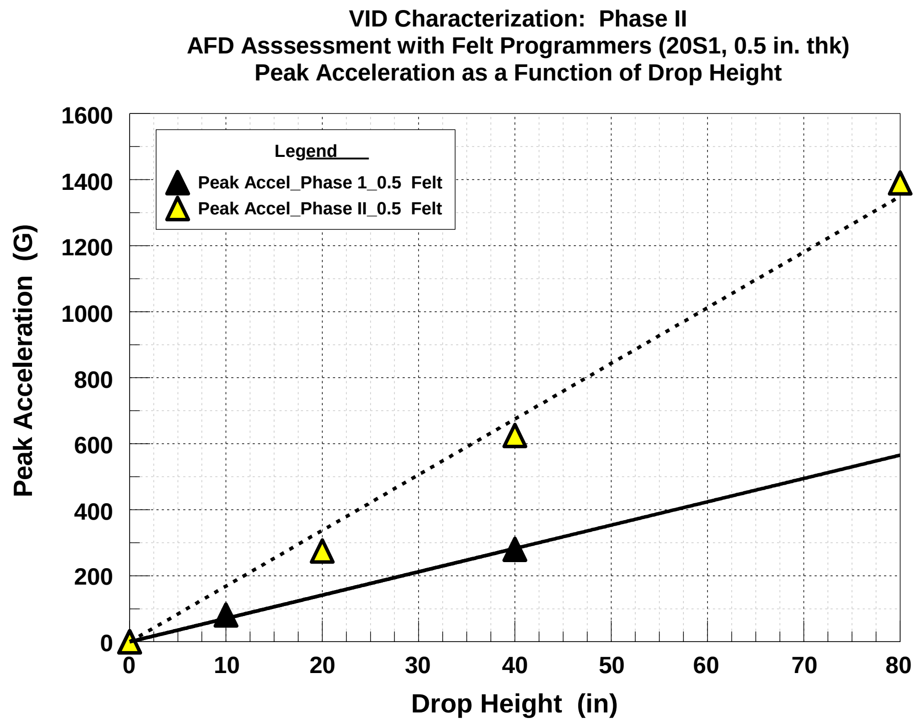

Figure 18. Peak Acceleration as Function of Drop Height w/AFD: 0.5 in. Felt Programmer

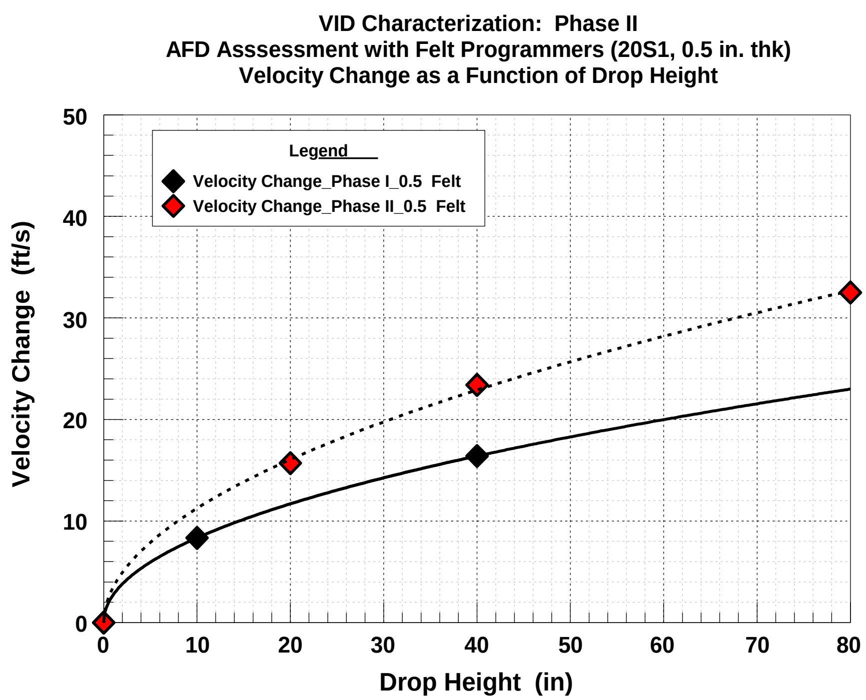

Figure 19. Velocity Change as Function of Drop Height w/AFD: 0.5 in. Felt Programmer

The data used to calculate the statistical means and standard deviations, for the acceleration and calculated velocity change data sets, was composed of data from VID tests 1124 through 1166, and used the same accelerometer packages from the Phase I study. A limited number of tests were conducted with the 0.5 in thick felt, and with the felt/plate/felt combination due to program time constraints. The narrow standard deviation values shown in the Table 6 highlight the repeatability of the VID test facility. All data comparison using the Phase I data used the 20S1 felt at the 0.5 and 1.0 inch thickness at the corresponding Phase II test conditions.

The plots generated from data showed that a linear equation provided a best fit regression line for the peak acceleration plots (Figures 15 and 17). The Phase II mean peak acceleration (G) as a function of drop height with the 1.0 in. thick felt samples was fit with a Linear equation defined as $y = 9.436*x$, which provided a Coefficient of Determination (COD) of $r^2 = 0.99$. The Phase II mean peak acceleration (G) as a function of drop height with the 0.5 in. thick felt samples was fit with a Linear equation defined as $y = 16.87*x$, which provided a Coefficient of Determination (COD) of $r^2 = 0.99$. The large number of data points in Phase II with the 1.0 in. felt strengthened the use of the linear model, and after review of the acceleration data plots from the Phase I report, a Linear model fit the data with a strong COD as well as the Power Series model that was used in that report.

The Phase I matched pair data sets (acceleration vs drop height with 1.0 in. felt and 0.5 in felt) relative to the Phase II data were also fit with a Linear model for consistency since there were only 3 points including the origin data point (0,0). The Phase I mean peak acceleration (G) as a function of drop height with the 1.0 in. thick felt samples was fit with a Linear equation defined as $y = 4.790*x$, which provided a Coefficient of Determination (COD) of $r^2 = 0.99$. The Phase I mean peak acceleration (G) as a function of drop height with the 0.5 in. thick felt samples was fit with a Linear equation defined as $y = 7.068*x$, which provided a Coefficient of Determination (COD) of $r^2 = 0.99$. The limited number of data points and the strong COD values for the Phase II data were the key drivers for using the Linear model.

The plots generated from the Table 6 data showed that a Power Series equation provided the best fit regression line for the velocity change plots (Figures 16 and 18). The Power Series equation is in agreement with the regression lines used for the velocity change data from the previously completed Phase I study. The Phase II velocity change as a function of drop height with the 1.0 in. thick felt samples was fit with a Power Series equation defined as $y = 2.91*x^{0.583}$, which provided a Coefficient of Determination (COD) of $r^2 = 0.99$. The Phase II velocity change as a function of drop height with the 0.5 in. thick felt samples was fit with a Power Series equation defined as $y = 3.46*x^{0.513}$, which provided a Coefficient of Determination (COD) of $r^2 = 0.99$. The excellent COD values for all the velocity change data also highlights the repeatability of the VID test facility, and also provide a tool for estimation of required test parameters.

The Phase I matched pair data sets (velocity change vs drop height with 1.0 in. felt and 0.5 in felt) relative to the Phase II data were also fit with a Power Series model for consistency since there were only 3 points including the origin data point (0,0). The Phase I velocity change as a function of drop height with the 1.0 in. thick felt samples was fit with a Power Series equation defined as $y = 2.84*x^{0.475}$. The Phase I velocity change as a function of drop height with the 0.5 in. thick felt samples was fit with a Power Series equation defined as $y = 2.71*x^{0.488}$. A

COD value was not reported since we only had three data points including the origin. The limited number of data points and the strong COD values for the Phase II data were the key drivers for using the Power Series model.

The regression lines identified in Figures 15 through 18 for the Phase I acceleration and velocity response as a function of drop height were individually plotted to provide prediction curves to determine the value for maximum acceleration and velocity change (ft/s) at the current maximum drop height of the VID facility which is approximately 80 inches. This was not required for the Phase II data since data was collected out to the 80 in. drop height.

One aspect of the test data that Figures 15 through 18 highlights is the variation in acceleration and velocity change response due to the installation of the AFD on the VID facility. This variation can be shown by calculation of the percent difference of the response with and without the AFD at corresponding drop heights. This also allows a further understanding of the effects of varying felt density on both peak acceleration and integrated velocity change with and without the AFD.

In order to calculate percent difference between data points collected with and without the AFD, the percent difference was always referenced to a baseline value, and for this study, our baseline value or $value_b$ was equal to the velocity or acceleration data point collected in Phase I without the AFD. The following equation was used to calculate the percent difference or Pd generated by using the AFD:

$$Pd = \frac{value - value_b}{value_b} \times 100$$

where value is the comparative data point from either the peak acceleration or velocity change data sets based on the testing using the AFD, and $value_b$ is the baseline reference value which is either the peak acceleration or velocity change data value when the AFD was not used in the first phase of tests. A positive Pd indicates that the acceleration or velocity increased with the use of the AFD. The percent difference data relative to the Phase I test data without the AFD is shown in Tables 7 and 8 for the peak acceleration and the velocity change data sets with the 1.0 inch thick felt programmers, and in Tables 9 and 10 for the 0.5 inch thick felt programmers. Values in the tables that are bold are projected values based on the linear or power series equations defined for that data set in this section above.

Table 7. Percent Difference in Peak Acceleration as a Function of the AFD: 1.0 Inch Thick Felt Programmer

Drop Height (in)	Phase I Peak Acceleration (G)	Phase II (AFD) Peak Acceleration (G)	Percent Difference (Pd)
10	57.4	***94.36***	64.4%
40	189.3	351.9	85.9%
80	***383.2***	822.6	115%

Table 8. Percent Difference in Velocity Change as a Function of the AFD: 1.0 Inch Thick Felt Programmer

Drop Height (in)	Phase I Velocity Change (ft/s)	Phase II (AFD) Velocity Change (ft/s)	Percent Difference (Pd)
10	8.49	***11.1***	30.7%
40	16.41	25.0	52.4%
80	***22.8***	39.0	71.1%

Table 9. Percent Difference in Peak Acceleration as a Function of the AFD: 0.5 Inch Thick Felt Programmer

Drop Height (in)	Phase I Peak Acceleration (G)	Phase II (AFD) Peak Acceleration (G)	Percent Difference (Pd)
10	81.2	***168.7***	108%
40	280.1	624.8	123%
80	***565.4***	1389.6	146%

Table 10. Percent Difference in Velocity Change as a Function of the AFD: 0.5 Inch Thick Felt Programmer

Drop Height (in)	Phase I Velocity Change (ft/s)	Phase II (AFD) Velocity Change (ft/s)	Percent Difference (Pd)
10	8.34	***11.27***	35.1%
40	16.41	23.4	42.6%
80	***22.9***	32.5	41.9%

The percent difference values for the peak acceleration and velocity change data indicate that the AFD had a very noticeable effect on them as the drop height increased while using the either the 1.0 inch thick or 0.5 inch thick felt programmers. The percent differences for the peak acceleration data steadily increased as the drop height increased with a maximum projected percent difference of approximately 115% and 146% at an 80 inch drop height for the 1.0 inch thick and 0.5 inch thick felt respectively. It is interesting to note that the projections of some of the acceleration data points using the Power Curves indicate that the peak acceleration would be doubled at even the lowest drop height tested (10 inches) for the 0.5 inch thick felt.

The percent differences for the velocity change data also steadily increased at each drop height with the use of the AFD. The velocity change increase exceeded 30% at all test conditions analyzed. It is interesting to note that the velocity change differences using the 0.5 inch thick felt appeared to be leveling off at around 40% difference starting at an approximate drop height of 40 inches. This may be indicating that this thinner felt sample has reached its limit on it capability to attenuate the energy from the drop as compared to the 1.0 inch thick felt samples.

The previous analysis of the acceleration time history, from the Phase I research effort with no AFD, indicated that felt thickness had a greater influence on the acceleration pulse shape when peak acceleration and TTP velocity change are considered. The indication was that as felt thickness decreased, the greater the effect on the pulse shape and the TTP velocity change decreased substantially. The felt thickness had negligible effect on the resultant velocity change at a given drop height.

The time history data from two different tests were used to plot the generated impact acceleration profiles as a function of time using the 20S1 1.0 inch thick felt programmers at a drop height of 40 inches. One waveform was from the AFD study (Phase II), and one waveform was from the previous no-AFD study (Phase I). The data from a 40 inch drop height was the only identical drop height where tests were conducted without and with the AFD fixture. These waveforms show the variation in pulse width as a function of using the AFD (Figure 20). The acceleration pulse width can also be used as an estimate of the TTP velocity where the velocity is calculated using the area under the acceleration curve. The plot in Figure 20 shows the TTP velocity decreased about a 2 ms, from approximately 7.3 ms to 5.3 ms, as a function of adding the AFD to the facility. This is similar to the results from the Red IMPAC programmer data set in Phase II, but with a larger time delta.

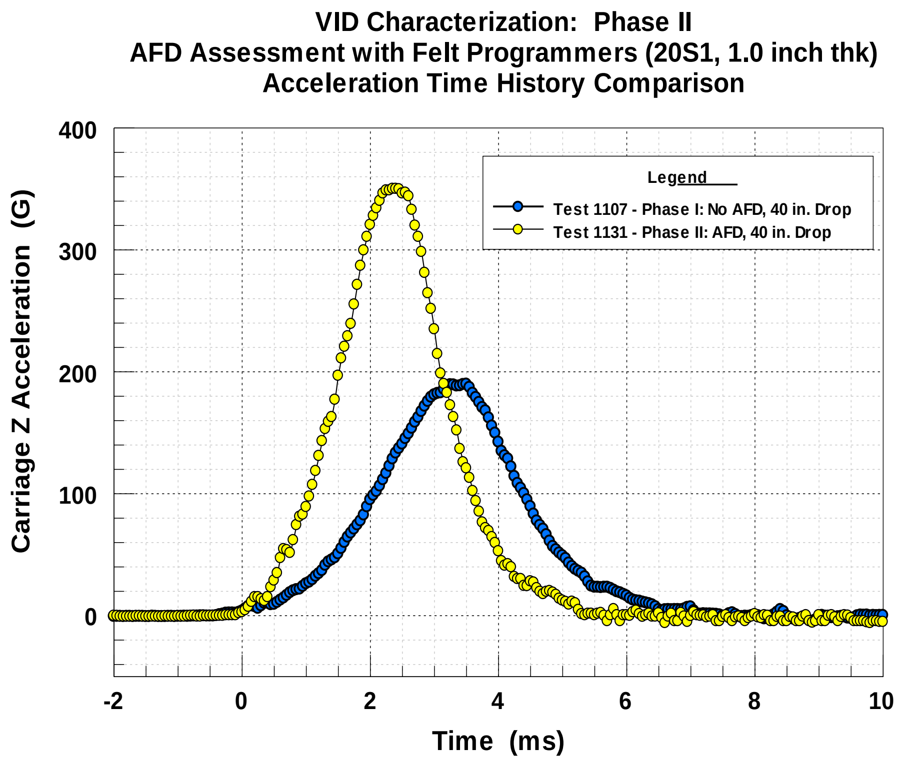

Figure 20. Acceleration Profiles With and Without AFD: Felt Programmer

7.5 AFD Assessment with Double Felt Programmer Configuration

An additional requirement from the WIAMan program was to determine whether the VID facility could produce velocity changes above 25 ft/s (7.6 m/s) with TTP values between 5 and 10 ms or greater. Velocity change data collected with the AFD indicated the VID could generate velocities approaching 40 ft/s (12.2 m/s), but the TTP values where decreasing at the higher drop heights when implementing the AFD. Results from the Phase I study indicated that a less dense, greater thickness felt sample would increase the TTP velocity change. A double-layer of felt was evaluated to determine if this configuration would also help alleviate the impact (decreased TTP velocity change) of using the AFD to generate greater resultant velocity changes.

The time history data from two different tests were used to plot the generated impact acceleration profiles as a function of time using the 20S1 1.0 inch thick felt programmers at a drop height of 80 inches. The test configuration for the waveform from the previous no-AFD study (Phase I) consisted of single layers of the felt programmer at the four impact locations under the VID carriage. The test configuration for the waveform from the current AFD study (Phase II) consisted of two layers of the felt programmer at the four impact locations under the VID carriage. A quarter inch aluminum plate of the same shape as the felt samples (12 inch by 12 inch square) was positioned between the felt to provide a serial material property configuration.

The data from a 80 inch drop height was the only identical drop height where tests were conducted with the two felt layer configurations. These waveforms show the variation in pulse width as a function of using the different felt layer configurations (Figure 21). The acceleration pulse width can also be used as an estimate of the TTP velocity where the velocity is calculated using the area under the acceleration curve. The plot in Figure 21 shows the TTP velocity increased about a 3 ms, from approximately 3.5 ms to between 6.5 and 7.0 ms, as a function of adding the second layer of felt to the configuration. This is almost a 100% increase in the TTP velocity, and indicates additional test configurations with less dense and greater thickness felt samples should be investigated.

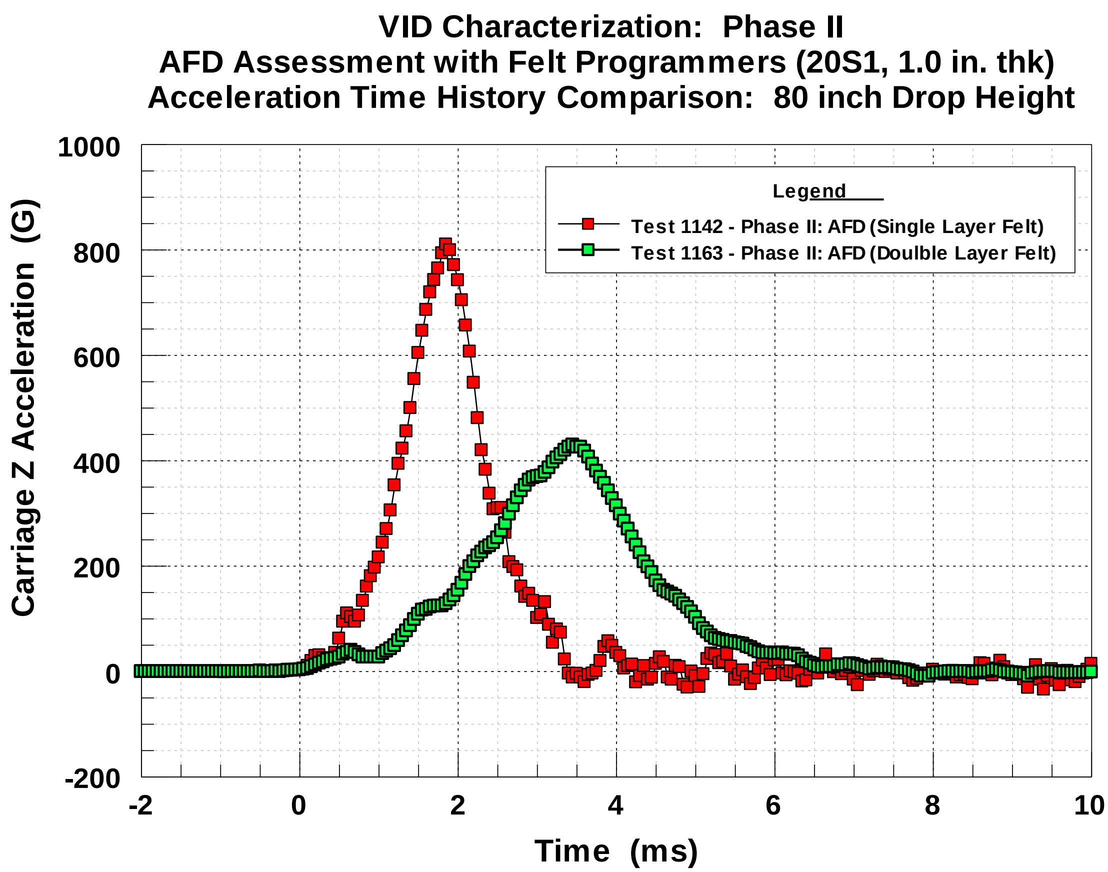

Figure 21. Acceleration Profiles With Felt Programmers: Single and Double Layers

8.0 SUMMARY AND CONCLUSIONS

Phase II of a research effort using the Vertical Impact Device (VID) located in Bldg 824, Wright Patterson AFB OH., was conducted to continue research of the facility's performance capabilities. The VID is a high-G impact test machine with seismic suspension, and is used to generate short duration, very high amplitude impact acceleration profiles to evaluate the effects on human and manikin subjects, and to define the effectiveness of operational and prototype protection concepts for the purpose of improving warfighter performance. The performance requirements for the VID were required to support the WIAMan program which had initial impact acceleration pulse requirements of over 300 G with pulse TTP values in the 5 to 10 ms range.

Phase I of the research effort with the VID used a parametric analysis with the objective to define and evaluate the performance effect of various impact attenuators on VID impact acceleration. Over 100 impact tests were completed during Phase I, and the dependent variables were defined as the high-density (red) urethane programmers, industrial felt density, and industrial felt thickness. The data analysis from Phase I indicated that the impact pulses had velocity changes that were below newly defined WIAMan program requirements, and a modification to the VID would need to be fabricated to generate velocity changes in excess of 32 ft/s (10 m/s).

Phase II of the research focused on the design and assessment of a test fixture developed to increase the velocity change currently generated by the VID facility in order to meet the new WIAMan program velocity change requirement. The Accelerated Freefall Device (AFD) test fixture was designed to meet this requirement, and was composed of a bungee cord system interfaced between the VID free-fall carriage and the reaction mass. The AFD design allowed for an initial velocity to be provided to the carriage at the moment it was released from the VID brake system. This initial velocity would provide for greater impact energy providing higher impact G-levels and velocity changes. The main objective of Phase II of the VID testing was to evaluate the efficiency of the AFD to generate the required WIAMan pulse shape using the VID facility. The approach was to conduct tests on the VID with the AFD installed using various energy attenuators, and then compare the acceleration and velocity change data to similar test conditions from the Phase I data set.

The first series of tests with the AFD installed on the VID were conducted using the red urethane (Red IMPAC) programmers on the drop carriage to evaluate the impact acceleration and velocity change as a function of drop height. The AFD progressively increased the peak acceleration and the velocity change with increasing drop height by 89% and 55% respectively at the maximum drop height tested. The generated prediction curve for velocity change indicated a velocity change of approximately 37.5 ft/s (11.4 m/s) at the currently estimated maximum drop height of 80 inches on the VID. The acceleration pulse width was used to estimate the TTP velocity change data and indicated that at a 50 inch drop height, the AFD affected the shape of the acceleration pulse, but only slightly influenced the TTP velocity change (No AFD: approximately 3 ms, with AFD: approximately 2.5 ms). This first test series indicated that the AFD in conjunction with the Red IMPAC programmers should be able to generate the required

velocity change (greater than 32 ft/s or 10 m/s); however, this was accomplished with a decreased velocity change TTP.

The second series of tests with the AFD installed on the VID were conducted using felt programmers positioned on top of the reaction mass to evaluate the impact acceleration and velocity change as a function of drop height. All felt tests were conducted with 20S1 felt density with thickness of either 0.5 or 1.0 inch. The AFD progressively increased the peak acceleration and the velocity change with increasing drop height, compared to the Phase I non-AFD configuration, by 86% and 52% respectively at a drop height of 40 inches for the 1.0 inch thick felt. The generated prediction curves for peak acceleration and velocity change from Phase I non-AFD increased those percent increase values to 115% and 71% respectively at a drop height of 80 inches. The velocity change with AFD at 80 inch drop height was 39 ft/s (11.9 m/s). The AFD progressively increased the peak acceleration and the velocity change with increasing drop height, compared to the Phase I non-AFD configuration, by 123% and 42% respectively at a drop height of 40 inches for the 0.5 inch thick felt. The generated prediction curves for peak acceleration and velocity change from Phase I non-AFD increased the peak acceleration percent increase value to 146% at a drop height of 80 inches. The percent increase value for velocity change did not change from 42%. The velocity change with AFD at 80 inch drop height was 33 ft/s (10.1 m/s). The acceleration pulse width was used as an estimate of the TTP velocity where the velocity is calculated using the area under the acceleration curve. Using Phase I and Phase II data from tests with the 1.0 inch thick, 20S1 felt, the data plot indicated that the TTP velocity decreased about a 2 ms, from approximately 7.3 ms to 5.3 ms, as a function of adding the AFD to the facility. This is similar to the results from the Red IMPAC programmer data set, but with a larger time delta. This second test series indicated that the AFD in conjunction with the felt programmers could generate the required velocity change (greater than 32 ft/s or 10 m/s); however, as with the Red IMPAC programmers, this was accomplished with a decreased velocity change TTP.

The third and final test series evaluated an additional requirement from the WIAMan program to determine whether the VID facility could produce velocity changes above 25 ft/s (7.6 m/s) with TTP values between 5 and 10 ms or greater. Current velocity change data collected with the AFD indicated the VID could generate velocities approaching 40 ft/s (12.2 m/s), but the TTP values were decreasing at the higher drop heights when implementing the AFD. A comparison was made between the time history data from two different tests using the generated impact acceleration profiles as a function of time with 20S1 1.0 inch thick felt programmers. The tests were conducted with a single layer felt sample and a double layer felt sample at a drop height of 80 inches. The TTP velocity increased about a 3 ms, from approximately 3.5 ms to between 6.5 and 7.0 ms, as a function of adding the second layer of felt to the configuration. This is almost a 100% increase in the TTP velocity while keeping the velocity change constant (approximately 36 ft/s). It is recommended that additional test configurations with less dense and greater thickness felt samples be investigated to develop a range of felt attenuation configurations to address different TTP velocity change requirements.

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GLOSSARY

ABP	Aircrew Biodynamics and Protection
AFRL	Air Force Research Laboratory
AFD	Accelerated Free-fall Device
COD	Coefficient of Determination
DAS	Data Acquisition System
DC	Direct Current
DoD	Department of Defense
DTS	Diversified Technical Systems
IED	Improvised Explosive Device
HPW	Human Performance Wing
NASA	National Aeronautics and Space Administration
USAF	United States Air Force
VID	Vertical Impact Device
WIAMan	Warrior Injury Assessment Manikin
WPAFB	Wright Patterson Air Force Base
WWI	World War I

APPENDIX A: ELECTRONIC DATA CHANNELS

PROGRAM: CHARACTERIZATION OF VERTICAL IMPACT DEVICE ACCELERATION PULSES USING PARAMETRIC ASSMENT (PHASE II)	TEST DATES: 7 June 2013; 10 June 2013; 21 - 24 June 2013; 1 July 2013; 16 - 17 July 2013; 24 July 2013; 4 October 2013; 8 - 9 October 2013; 18 October 2013; 19 - 20 November 2013; 9 - 13 December 2013; 15-16 January 2014
STUDY NUMBER: 201306	TEST NUMBERS: 1113-1129; 1130-1135; 1136-1146; 1147-1149; 1150-1159; 1160-1166; 1167-1168: 1169-1200; 1201-1209; 1210-1219; 1220-1241; 1152-1167
FACILITY: VID	SAMPLE RATE: 20 Khz
DATA COLLECTION SYSTEM: TDAS G5 sr# 5M0022	FILTER FREQUENCY: 2 Khz
	TRANSDUCER RANGE (VOLTS): +/- 5V

DATA CHANNEL	DATA POINT	TRANSDUCER MFG. & MODEL	SERIAL NUMBER	PRE-CAL		POST-CAL		% Δ	DAS SENSITIVITY	BRIDGE	FULL SCALE	NOTES
				DATE	SENS	DATE	SENS					
1	CARRIAGE X ACCCEL (G)	ENTRAN EGE-72-200D	01G01G 13-NO7	13-Mar-13	2.1250 mv/g at 10V exc	24-Jan-14	2.1889 mv/g at 10V exc	3.0	.21250 mv/v/g	FULL	200 G	Tests 1113-1241;1252-1267
2	CARRIAGE Y ACCCEL (G)	ENTRAN EGE-72-200D	93C93C 19-R10	15-Feb-13	2.1679 mv/g at 10V exc	24-Jan-14	2.2652 mv/g at 10V exc	3.0	.21679 mv/v/g	FULL	200 G	Tests 1113-1241;1252-1267
3	CARRIAGE Z ACCCEL (G)	MEAS SPEC EGCS-S425-2000	A011331	29-Apr-13	.0832 mv/g at 10V exc	24-Jan-14	.0857 mv/g at 10V exc	3.0	.00832 mv/v/g	FULL	2000 G	Tests 1113-1241;1252-1267
4	CARRIAGE X1 ACCCEL (G)	ENTRAN EGE-72-200D	93C93C 19-R14	15-Feb-13	2.2958 mv/g at 10V exc	24-Jan-14	2.3651 mv/g at 10V exc	3.0	.22958 mv/v/g	FULL	200 G	Tests 1113-1168;
5	CARRIAGE Y1 ACCCEL (G)	ENTRAN EGE-72-200D	93C93C 19-R13	13-Mar-13	2.3088 mv/g at 10V exc	24-Jan-14	2.4131 mv/g at 10V exc	3.0	.23088 mv/v/g	FULL	200 G	Tests 1113-1168;
6	CARRIAGE Z1 ACCCEL (G)	MEAS SPEC EGCS-S425-2000	A011337	29-Apr-13	.0825 mv/g at 10V exc	24-Jan-14	.0848 mv/g at 10V exc	2.8	.00825 mv/v/g	FULL	2000 G	Tests 1113-1168;
7	CARRIAGE X2 ACCCEL (G)	ENTRAN EGE-72-200D	93C93C 19-R12	13-Mar-13	2.2415 mv/g at 10V exc	24-Jan-14	2.3778 mv/g at 10V exc	3.0	.22415 mv/v/g	FULL	200 G	Tests 1113-1168;
8	CARRIAGE Y2 ACCCEL (G)	ENTRAN EGE-72-200D	93C93C 19-R11	13-Mar-13	2.2002 mv/g at 10V exc	24-Jan-14	2.3093 mv/g at 10V exc	3.0	.22002 mv/v/g	FULL	200 G	Tests 1113-1168;
9	CARRIAGE Z2 ACCCEL (G)	MEAS SPEC EGCS-S425-2000	A011338	29-Apr-13	.0863 mv/g at 10V exc	24-Jan-14	.0888 mv/g at 10V exc	2.9	.00863 mv/v/g	FULL	2000 G	Tests 1113-1168;

APPENDIX B. AFD ASSESSMENT WITH RED PROGRAMMER: TEST-BY-TEST SUMMARY

- **Test 1113:** Cell A, Test 1; Red IMPAC Programmer; Drop Height = 20 in., Peak G level = No data, Integrated Velocity Change = No data, TTP Acceleration = No data, TTP Velocity = No data.
  No Test- No data was recorded nor produced; retest.

- **Test 1114:** Cell A, Test 2; Red IMPAC Programmer; Drop Height = 20 in., Peak G level = 338.26, Integrated Velocity Change = 17.1 ft/s, Measured Velocity Change = 9.27 ft/s, TTP Acceleration = 1.5 ms, TTP Velocity = 9.2 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **Test 1115:** Cell A, Test 3; Red IMPAC Programmer; Drop Height = 20 in., Peak G level = 342, Integrated Velocity Change = 17.17 ft/s, Measured Velocity Change = 10.42 ft/s, TTP Acceleration = 1.5 ms, TTP Velocity = 9.2 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **Test 1116:** Cell A, Test 4; Red IMPAC Programmer; Drop Height = 20 in., Peak G level = 330.54, Integrated Velocity Change = 17.09 ft/s, Measured Velocity Change = 12.83 ft/s, TTP Acceleration = 1.6 ms, TTP Velocity = 9.3 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **Test 1117:** Cell B, Test 1; Red IMPAC Programmer; Drop Height = 30 in., Peak G level = 471, Integrated Velocity Change = 21.35 ft/s, Measured Velocity Change = 11.96 ft/s, TTP Acceleration = 1.4 ms, TTP Velocity = 8.9 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **Test 1118:** Cell B, Test 2; Red IMPAC Programmer; Drop Height = 30 in., Peak G level = 476.72, Integrated Velocity Change = 21.4 ft/s, Measured Velocity Change = 12.02 ft/s, TTP Acceleration = 1.5 ms, TTP Velocity = 8.9 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **Test 1119:** Cell B, Test 3; Red IMPAC Programmer; Drop Height = 30 in., Peak G level = 475.65, Integrated Velocity Change = 21.47 ft/s, Measured Velocity Change = 12.12 ft/s, TTP Acceleration = 1.5 ms, TTP Velocity = 8.9 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **<u>Test 1120</u>:** Cell C, Test 1; Red IMPAC Programmer; Drop Height = 40 in., Peak G level = 660.4, Integrated Velocity Change = 25.21 ft/s, Measured Velocity Change = 13.78 ft/s, TTP Acceleration = 1.3 ms, TTP Velocity = 8.8 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **<u>Test 1121</u>:** Cell C, Test 2; Red IMPAC Programmer; Drop Height = 40 in., Peak G level = 665.52, Integrated Velocity Change = 25.31 ft/s, Measured Velocity Change = 13.67 ft/s, TTP Acceleration = 1.3 ms, TTP Velocity = 8.9 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **<u>Test 1122</u>:** Cell C, Test 3; Red IMPAC Programmer; Drop Height = 40 in., Peak G level = 662.87, Integrated Velocity Change = 25.28 ft/s, Measured Velocity Change = 13.61 ft/s, TTP Acceleration = 1.3 ms, TTP Velocity = 8.8 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **<u>Test 1123</u>:** Cell D, Test 1; Red IMPAC Programmer; Drop Height = 50 in., Peak G level = 832.75, Integrated Velocity Change = 28.65 ft/s, Measured Velocity Change = 15.06 ft/s, TTP Acceleration = 1.2 ms, TTP Velocity = 8.7 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

APPENDIX C: SAMPLE DATA SHEETS – RED URETHANE PROGRAMMERS

Test 1114: Cell A; Drop Height = 20 in., Peak G level = 338.26, Integrated Velocity Change = 17.1 ft/s, Measured Velocity Change = 9.27 ft/s, TTP Acceleration = 1.5 ms, TTP Velocity = 9.2 ms.

Test 1123: Cell D, Drop Height = 50 in., Peak G level = 832.75, Integrated Velocity Change = 28.65 ft/s, Measured Velocity Change = 15.06 ft/s, TTP Acceleration = 1.2 ms, TTP Velocity = 8.7 ms.

201306 Test: 1114 Test Date: 130607 Subj: RED BUMPER Wt: .0
Nom G: 300.0 Cell: A

Data ID	Immediate Preimpact	Maximum Value	Minimum Value	Time Of Maximum	Time Of Minimum
Reference Mark Time (Ms)				0.1	
Drop Height (In)		20.00			
Impact Rise Time (Ms)				1.5	
Impact Duration (Ms)				3.5	
Velocity Change (Ft/Sec)		9.72			
CARRIAGE X ACCEL (G)	-0.01	24.05	-23.23	1.8	1.0
CARRIAGE Y ACCEL (G)	0.01	9.87	-4.12	2.7	6.6
CARRIAGE Z ACCEL (G)	-0.94	338.26	-11.43	1.5	3.9
CARRIAGE RES ACCEL (G)	0.95	338.76	0.37	1.5	27.4
INTEGRATED ACCEL (FT/SEC)	9.25	9.72	-7.38	1.2	9.2
CARRIAGE X1 ACCEL (G)	0.14	4.81	-46.77	3.6	1.4
CARRIAGE Y1 ACCEL (G)	0.13	13.96	-52.87	3.1	2.0
CARRIAGE Z1 ACCEL (G)	-0.91	332.69	-14.09	1.7	8.0
CARRIAGE RES1 ACCEL (G)	0.94	337.29	0.18	1.7	14.8
CARRIAGE X2 ACCEL (G)	0.08	5.57	-30.94	4.4	1.7
CARRIAGE Y2 ACCEL (G)	0.01	19.50	-9.30	2.1	2.9
CARRIAGE Z2 ACCEL (G)	-0.96	347.21	-12.10	1.6	4.0
CARRIAGE RES2 ACCEL (G)	0.96	348.35	0.45	1.6	0.0
TOP LEFT RETRACTIONFORCE (LB	0.18	375.54	-128.51	25.4	14.3
TOP RIGHT RETRACTION FORCE (	4.16	425.25	-79.26	31.4	6.6

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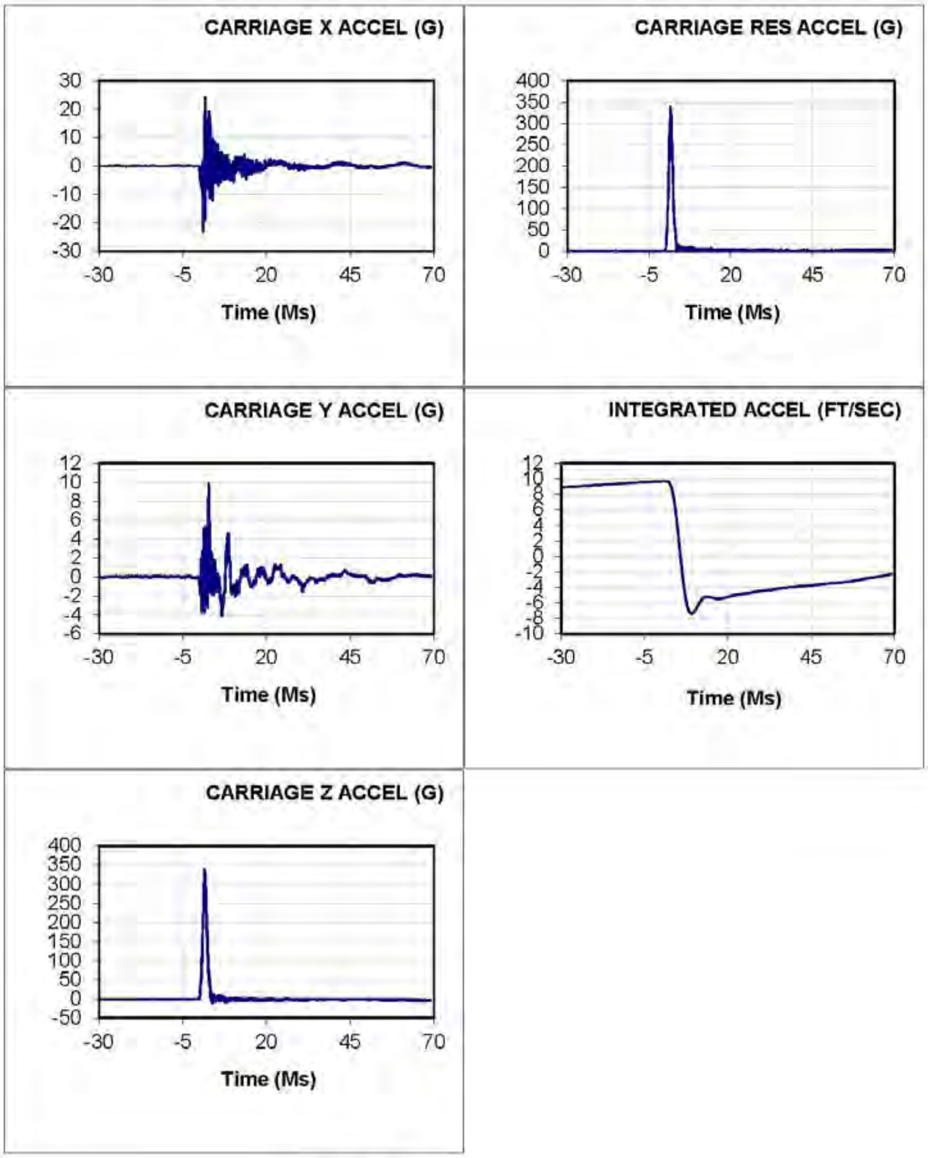
201306 Test: 1114 Test Date: 130607 Subj: RED BUMPER Cell: A



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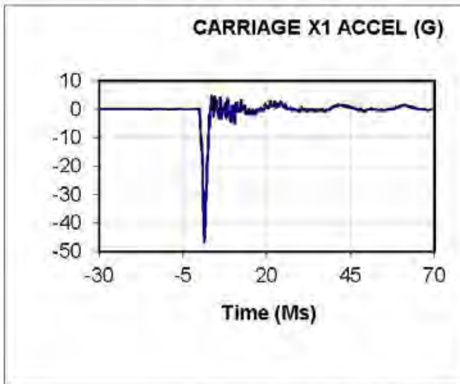
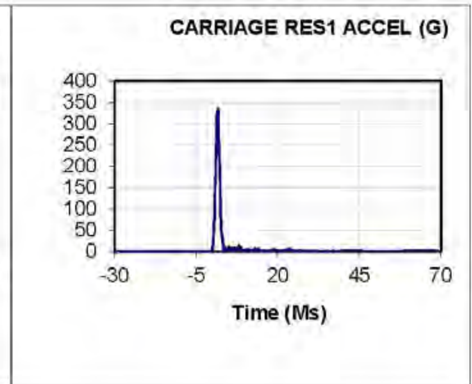
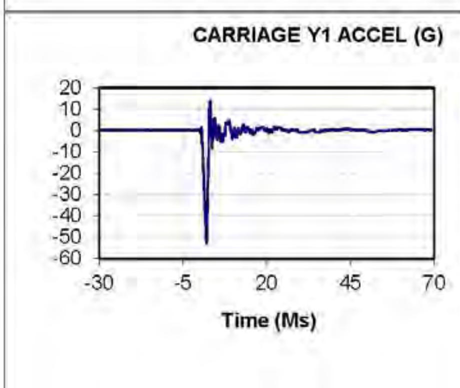
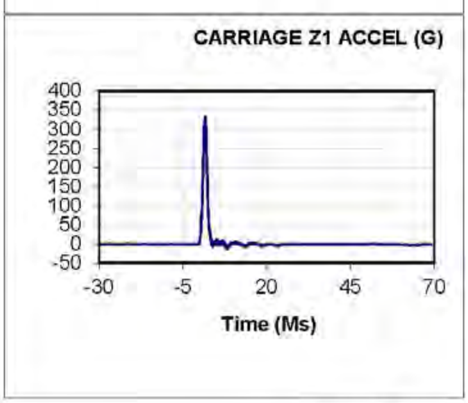
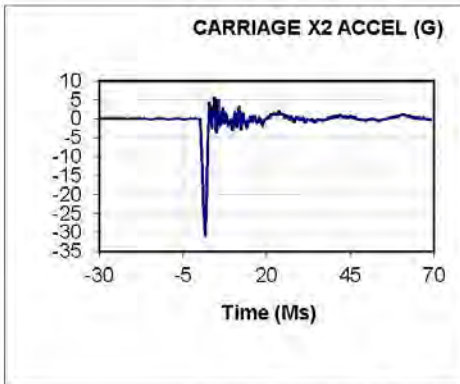

CARRIAGE X1 ACCEL (G)
10
0
-10
-20
-30
-40
-50
-30
-5
20
45
70
Time (Ms)

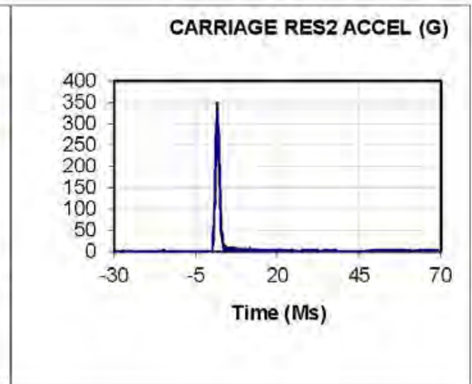

CARRIAGE RES1 ACCEL (G)
400
350
300
250
200
150
100
50
0
-30
-5
20
45
70
Time (Ms)

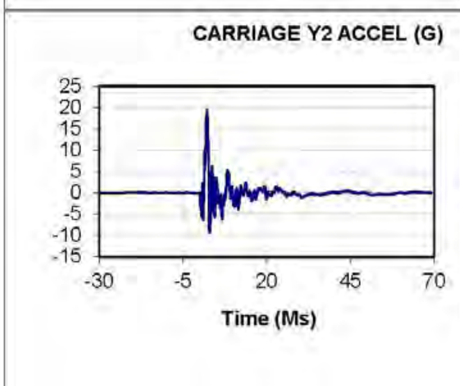

CARRIAGE Y1 ACCEL (G)
20
10
0
-10
-20
-30
-40
-50
-60
-30
-5
20
45
70
Time (Ms)

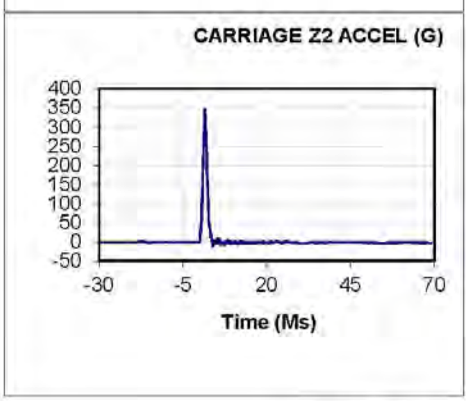

CARRIAGE Z1 ACCEL (G)
400
350
300
250
200
150
100
50
0
-50
-30
-5
20
45
70
Time (Ms)

201306 Test: 1114 Test Date: 130607 Subj: RED BUMPER Cell: A









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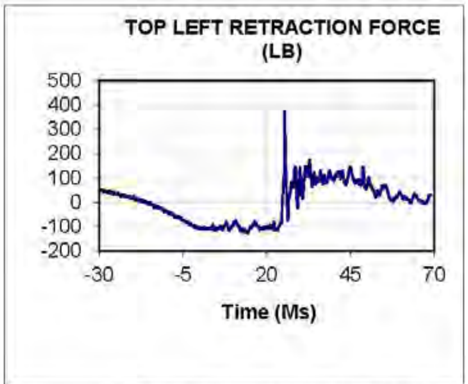
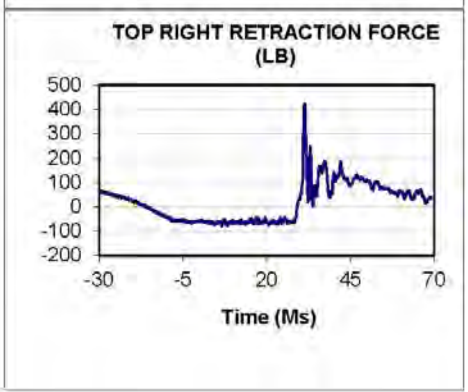
201306 Test: 1114 Test Date: 130607 Subj: RED BUMPER Cell: A





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201306 Test: 1123 Test Date: 130607 Subj: RED BUMPER Wt: .0
Nom G: 800.0 Cell: D

Data ID	Immediate Preimpact	Maximum Value	Minimum Value	Time Of Maximum	Time Of Minimum
Reference Mark Time (Ms)				0.0	
Drop Height (In)		50.00			
Impact Rise Time (Ms)				1.2	
Impact Duration (Ms)				2.7	
Velocity Change (Ft/Sec)		15.06			
CARRIAGE X ACCEL (G)	0.01	68.18	-75.59	1.3	0.8
CARRIAGE Y ACCEL (G)	-0.01	19.07	-16.76	1.5	0.4
CARRIAGE Z ACCEL (G)	-0.99	832.75	-74.77	1.2	3.0
CARRIAGE RES ACCEL (G)	1.00	832.87	0.32	1.2	50.3
INTEGRATED ACCEL (FT/SEC)	14.50	15.06	-13.59	1.0	8.7
CARRIAGE X1 ACCEL (G)	0.14	16.11	-97.37	3.0	1.1
CARRIAGE Y1 ACCEL (G)	0.13	63.01	-156.08	2.3	1.6
CARRIAGE Z1 ACCEL (G)	-1.10	815.37	-55.34	1.3	2.8
CARRIAGE RES1 ACCEL (G)	1.12	827.91	0.24	1.3	56.3
CARRIAGE X2 ACCEL (G)	0.07	15.02	-71.64	2.3	1.2
CARRIAGE Y2 ACCEL (G)	-0.06	45.42	-93.64	2.4	1.6
CARRIAGE Z2 ACCEL (G)	-0.97	778.90	-42.18	1.1	2.9
CARRIAGE RES2 ACCEL (G)	0.98	782.02	0.38	1.1	19.7
TOP LEFT RETRACTION FORCE (L	9.91	440.34	-147.61	33.0	13.4
TOP RIGHT RETRACTION FORCE (	26.91	2078.65	-89.36	38.8	6.0

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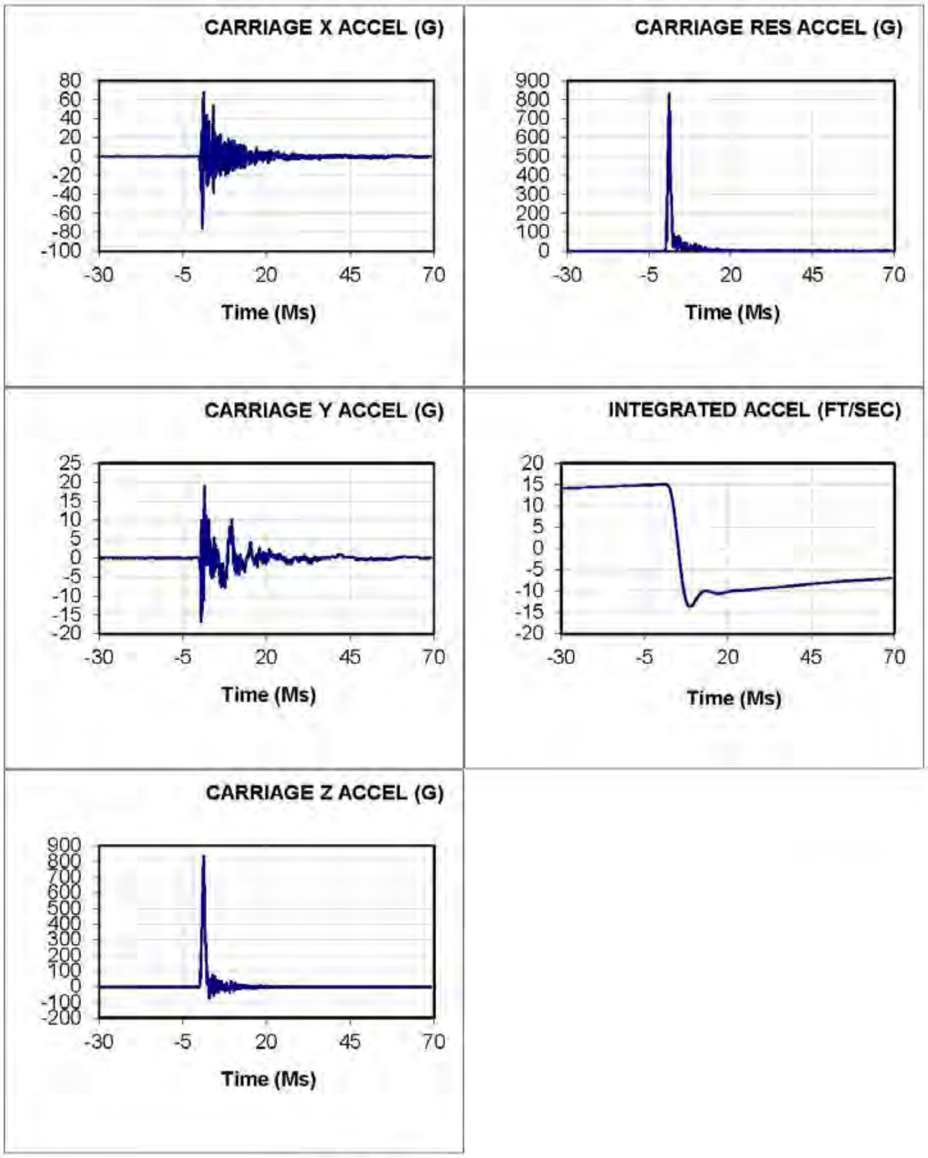
201306 Test: 1123 Test Date: 130607 Subj: RED BUMPER Cell: D



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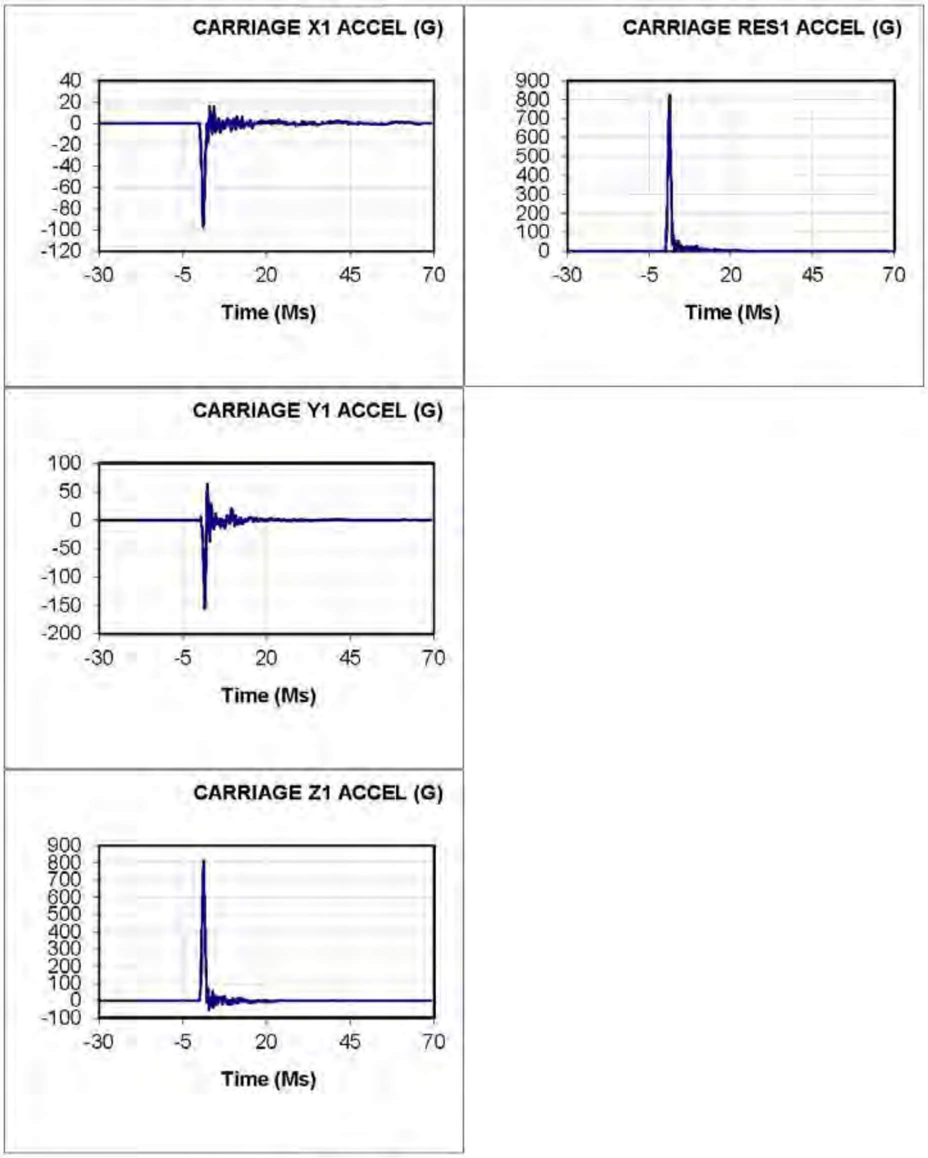
201306 Test: 1123 Test Date: 130607 Subj: RED BUMPER Cell: D



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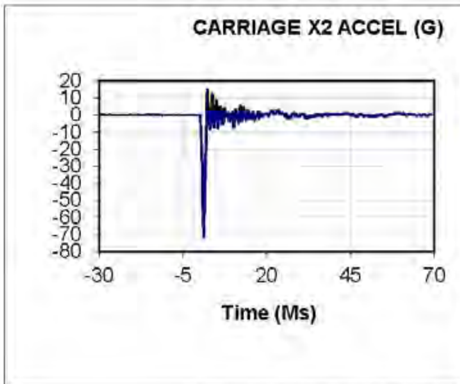
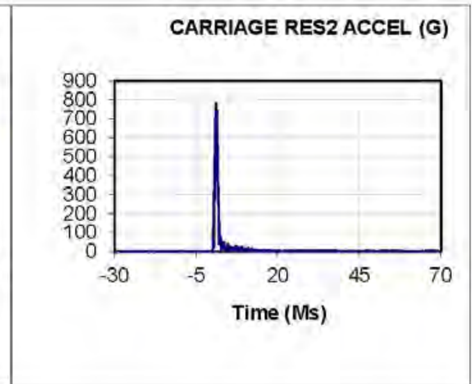
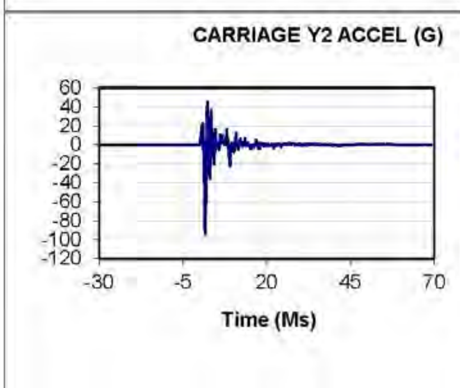
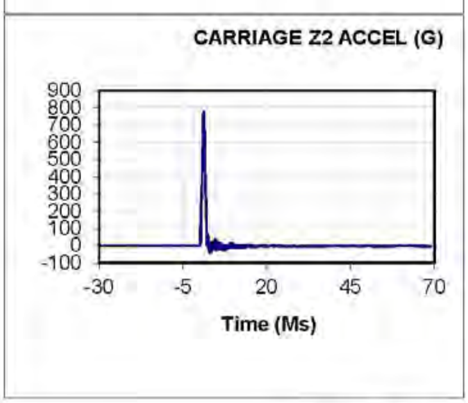
201306 Test: 1123 Test Date: 130607 Subj: RED BUMPER Cell: D









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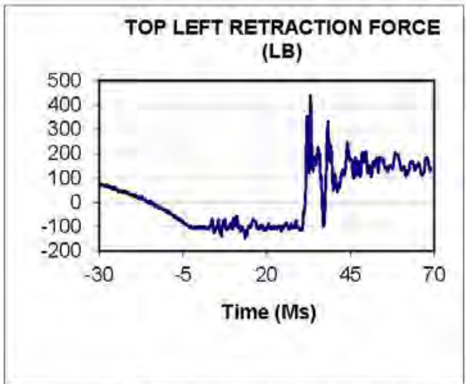
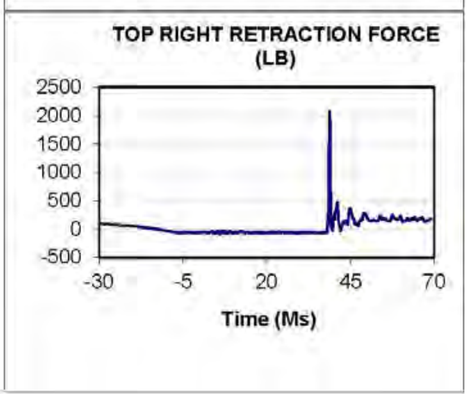
201306 Test: 1123 Test Date: 130607 Subj: RED BUMPER Cell: D





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APPENDIX D. AFD ASSESSMENT WITH FELT PROGRAMMERS: TEST-BY-TEST SUMMARY

- **<u>Test 1124</u>:** Cell E, Test 1; Felt Density 2051 (1.0 in.); Drop Height = 20 in., Peak G level = 176.64, Integrated Velocity Change = 16.87 ft/s, Measured Velocity Change = 10.15 ft/s, TTP Acceleration = 2.6 ms, TTP Velocity = 10.5 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **<u>Test 1125</u>:** Cell E, Test 2; Felt Density 2051 (1.0 in.); Drop Height = 20 in., Peak G level = 182, Integrated Velocity Change = 17.02 ft/s, Measured Velocity Change = 10.34 ft/s, TTP Acceleration = 2.7 ms, TTP Velocity = 10.6 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **<u>Test 1126</u>:** Cell E, Test 3; Felt Density 2051 (1.0 in.); Drop Height = 20 in., Peak G level = 184.94, Integrated Velocity Change = 17.04 ft/s, Measured Velocity Change = 10.15 ft/s, TTP Acceleration = 2.8 ms, TTP Velocity = 10.6 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **<u>Test 1127</u>:** Cell F, Test 1; Felt Density 2051 (1.0 in.); Drop Height = 30 in., Peak G level = 270.15, Integrated Velocity Change = 21.53 ft/s, Measured Velocity Change = 12.28 ft/s, TTP Acceleration = 2.5 ms, TTP Velocity = 10.2 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **<u>Test 1128</u>:** Cell F, Test 2; Felt Density 2051 (1.0 in.); Drop Height = 30 in., Peak G level = 273.23, Integrated Velocity Change = 21.66 ft/s, Measured Velocity Change = 11.61 ft/s, TTP Acceleration = 2.5 ms, TTP Velocity = 10.2 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **<u>Test 1129</u>:** Cell F, Test 3; Felt Density 2051 (1.0 in.); Drop Height = 30 in., Peak G level = 276.26, Integrated Velocity Change = 21.67 ft/s, Measured Velocity Change = 12.18 ft/s, TTP Acceleration = 2.5 ms, TTP Velocity = 10.2 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **<u>Test 1130</u>:** Cell G, Test 1; Felt Density 2051 (1.0 in.); Drop Height = 40 in., Peak G level = 348.28, Integrated Velocity Change = 24.98 ft/s, Measured Velocity Change = 13.64 ft/s, TTP Acceleration = 2.2 ms, TTP Velocity = 10 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **<u>Test 1131</u>:** Cell G, Test 2; Felt Density 2051 (1.0 in.); Drop Height = 40 in., Peak G level = 350.01, Integrated Velocity Change = 25 ft/s, Measured Velocity Change = 12.71 ft/s, TTP Acceleration = 2.4 ms, TTP Velocity = 10.1 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **<u>Test 1132</u>:** Cell G, Test 3; Felt Density 2051 (1.0 in.); Drop Height = 40 in., Peak G level = 357.36, Integrated Velocity Change = 24.97 ft/s, Measured Velocity Change = 13.87 ft/s, TTP Acceleration = 2.4 ms, TTP Velocity = 10.1 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **<u>Test 1133</u>:** Cell H, Test 1; Felt Density 2051 (1.0 in.); Drop Height = 50 in., Peak G level = 448.34, Integrated Velocity Change = 28.19 ft/s, Measured Velocity Change = 14.71 ft/s, TTP Acceleration = 2.1 ms, TTP Velocity = 9.8 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **<u>Test 1134</u>:** Cell H, Test 2; Felt Density 2051 (1.0 in.); Drop Height = 50 in., Peak G level = 460.76, Integrated Velocity Change = 28.23 ft/s, Measured Velocity Change = 14.82 ft/s, TTP Acceleration = 2.2 ms, TTP Velocity = 9.8 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **<u>Test 1135</u>:** Cell H, Test 3; Felt Density 2051 (1.0 in.); Drop Height = 50 in., Peak G level = 460.7, Integrated Velocity Change = 28.1 ft/s, Measured Velocity Change = 14.8 ft/s, TTP Acceleration = 2.2 ms, TTP Velocity = 9.8 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved.

- **<u>Test 1136</u>:** Cell I, Test 1; Felt Density 2051 (1.0 in.); Drop Height = 60 in., Peak G level = 494.48, Integrated Velocity Change = 30.86 ft/s, Measured Velocity Change = 16.27 ft/s, TTP Acceleration = 2.1 ms, TTP Velocity = 9.8 ms.
  No Test- No data was recorded nor produced for the Peak G level; retest.

- **<u>Test 1137</u>:** Cell I, Test 2; Felt Density 2051 (1.0 in.); Drop Height = 60 in., Peak G level = 526.24, Integrated Velocity Change = 31.01 ft/s, Measured Velocity Change = 15.92 ft/s, TTP Acceleration = 2 ms, TTP Velocity = 9.6 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator.

- **<u>Test 1138</u>:** Cell I, Test 3; Felt Density 2051 (1.0 in.); Drop Height = 60 in., Peak G level = 533.86, Integrated Velocity Change = 30.84 ft/s, Measured Velocity Change = 16.52 ft/s, TTP Acceleration = 2.1 ms, TTP Velocity = 9.6 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator.

- **<u>Test 1139</u>:** Cell J, Test 1; Felt Density 2051 (1.0 in.); Drop Height = 70 in., Peak G level = 649.72, Integrated Velocity Change = 33.59 ft/s, Measured Velocity Change = 17.26 ft/s, TTP Acceleration = 1.9 ms, TTP Velocity = 9.6 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator.

- **<u>Test 1140</u>:** Cell J, Test 2; Felt Density 2051 (1.0 in.); Drop Height = 70 in., Peak G level = 642.18, Integrated Velocity Change = 33.1 ft/s, Measured Velocity Change = 17.54 ft/s, TTP Acceleration = 2 ms, TTP Velocity = 9.6 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator.

- **<u>Test 1141</u>:** Cell K, Test 1; Felt Density 2051 (1.0 in.); Drop Height = 80 in., Peak G level = 788.82, Integrated Velocity Change = 36.3 ft/s, Measured Velocity Change = 18.21 ft/s, TTP Acceleration = 1.9 ms, TTP Velocity = 9.4 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator.

- **<u>Test 1142</u>:** Cell K, Test 2; Felt Density 2051 (1.0 in.); Drop Height = 80 in., Peak G level = 810.08, Integrated Velocity Change = 36.32 ft/s, Measured Velocity Change = 18.22 ft/s, TTP Acceleration = 1.9 ms, TTP Velocity = 9.4 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator.

- **<u>Test 1143</u>:** Cell K1, Test 1; Felt Density 2051 (1.0 in.); Drop Height = 80 in., Peak G level = 792.05, Integrated Velocity Change = 48.12 ft/s, Measured Velocity Change = 48.12 ft/s, TTP Acceleration = 1.9 ms, TTP Velocity = 9.5 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator. Base pressure increased from 1800 to 2200 psi.

- **Test 1144:** Cell K1, Test 2; Felt Density 2051 (1.0 in.); Drop Height = 80 in., Peak G level = 852.6, Integrated Velocity Change = 37.11 ft/s, Measured Velocity Change = 19.99 ft/s, TTP Acceleration = 1.8 ms, TTP Velocity = 9.4 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator. Base pressure increased from 1800 to 2200 psi.

- **Test 1145:** Cell K2, Test 1; Felt Density 2051 (1.0 in.); Drop Height = 80 in., Peak G level = 869.25, Integrated Velocity Change = 37.31 ft/s, Measured Velocity Change = 20.26 ft/s, TTP Acceleration = 2 ms, TTP Velocity = 9.5 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator. Base pressure increased from 1800 to 2200 psi with a sample rate of 10k.

- **Test 1146:** Cell K3, Test 1; Felt Density 2051 (0.5 in.); Drop Height = 80 in., Peak G level = 1220.16, Integrated Velocity Change = 35.82 ft/s, Measured Velocity Change = 35.82 ft/s, TTP Acceleration = 1.1 ms, TTP Velocity = 17.8 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator. Base pressure increased from 1800 to 2200 psi; filtered at 120 Hz.

- **Test 1147:** Cell K4, Test 1; Felt Density 2051 (0.5 in.); Drop Height = 80 in., Peak G level = 1246.25, Integrated Velocity Change = 35.17 ft/s, Measured Velocity Change = 17.61 ft/s, TTP Acceleration = 1.1 ms, TTP Velocity = 8.6 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator. Base pressure decreased back to 1800.

- **Test 1148:** Cell K4, Test 2; Felt Density 2051 (0.5 in.); Drop Height = 80 in., Peak G level = 1244.88, Integrated Velocity Change = 17.67 ft/s, Measured Velocity Change = 17.67 ft/s, TTP Acceleration = 1 ms, TTP Velocity = 8.6 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator. Base pressure decreased back to 1800.

- **Test 1149:** Cell K3, Test 2; Felt Density 2051 (0.5 in.); Drop Height = 80 in., Peak G level = 1254.77, Integrated Velocity Change = 34.08 ft/s, Measured Velocity Change = 17.9 ft/s, TTP Acceleration = 1 ms, TTP Velocity = 8.6 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator. Base pressure increased from 1800 to 2200 psi.

- **<u>Test 1150</u>:** Cell O1, Test 1; Felt Density 2051 (0.5 in.); Drop Height = 20 in., Peak G level = 273.97, Integrated Velocity Change = 15.76 ft/s, Measured Velocity Change = 10.32 ft/s, TTP Acceleration = 1.8 ms, TTP Velocity = 9.4 ms.
Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator. Base pressure increased from 1800 to 2200 psi; Velocity Sensor Tests.

- **<u>Test 1151</u>:** Cell O1, Test 2; Felt Density 2051 (0.5 in.); Drop Height = 20 in., Peak G level = 274.88, Integrated Velocity Change = 15.69 ft/s, Measured Velocity Change = 9.75 ft/s, TTP Acceleration = 1.8 ms, TTP Velocity = 9.4 ms.
Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator; Velocity Sensor Tests.

- **<u>Test 1152</u>:** Cell O1, Test 3; Felt Density 2051 (0.5 in.); Drop Height = 20 in., Peak G level = 275.61, Integrated Velocity Change = 15.68 ft/s, Measured Velocity Change = 9.97 ft/s, TTP Acceleration = 1.8 ms, TTP Velocity = 9.4 ms.
Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator; Velocity Sensor Tests.

- **<u>Test 1153</u>:** Cell O2, Test 1; Felt Density 2051 (0.5 in.); Drop Height = 40 in., Peak G level = 620.45, Integrated Velocity Change = 23.47 ft/s, Measured Velocity Change = 14.22 ft/s, TTP Acceleration = 1.4 ms, TTP Velocity = 8.9 ms.
Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator; Velocity Sensor Tests.

- **<u>Test 1154</u>:** Cell O2, Test 2; Felt Density 2051 (0.5 in.); Drop Height = 40 in., Peak G level = 620.79, Integrated Velocity Change = 23.3 ft/s, Measured Velocity Change = 14.27 ft/s, TTP Acceleration = 1.4 ms, TTP Velocity = 8.9 ms.
Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator; Velocity Sensor Tests.

- **<u>Test 1155</u>:** Cell O2, Test 3; Felt Density 2051 (0.5 in.); Drop Height = 40 in., Peak G level = 633.17, Integrated Velocity Change = 23.4 ft/s, Measured Velocity Change = 14.07 ft/s, TTP Acceleration = 1.5 ms, TTP Velocity = 8.9 ms.
Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator; Velocity Sensor Tests.

- **<u>Test 1156</u>:** Cell O3, Test 1; Felt Density 2051 (0.5 in.); Drop Height = 80 in., Peak G level = 1245.64, Integrated Velocity Change = 33.42 ft/s, Measured Velocity Change = 18.12 ft/s, TTP Acceleration = 1 ms, TTP Velocity = 8.6 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator; Velocity Sensor Tests.

- **<u>Test 1157</u>:** Cell O3, Test 2; Felt Density 2051 (0.5 in.); Drop Height = 80 in., Peak G level = 1531.56, Integrated Velocity Change = 33.91 ft/s, Measured Velocity Change = 23.84 ft/s, TTP Acceleration = 1.1 ms, TTP Velocity = 8.6 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator; Velocity Sensor Tests.

- **<u>Test 1158</u>:** Cell O3, Test 3; Felt Density 2051 (0.5 in.); Drop Height = 80 in., Peak G level = 1582.08, Integrated Velocity Change = 34.12 ft/s, Measured Velocity Change = 14.68 ft/s, TTP Acceleration = 1.1 ms, TTP Velocity = 8.6 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator; Velocity Sensor Tests.

- **<u>Test 1159</u>:** Cell O4, Test 1; Felt Density 2051 (0.5 in.); Drop Height = 80 in., Peak G level = 1637.75, Integrated Velocity Change = 34.23 ft/s, Measured Velocity Change = 24.29 ft/s, TTP Acceleration = 1.1 ms, TTP Velocity = 8.6 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator. Base pressure decreased to 1500 psi.

- **<u>Test 1160</u>:** Cell O5, Test 1; Felt Density 2051 (0.5 in.); Drop Height = 80 in., Peak G level = 1542.97, Integrated Velocity Change = 34 ft/s, Measured Velocity Change = 28.28 ft/s, TTP Acceleration = 1.1 ms, TTP Velocity = 8.6 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator. Base pressure decreased to 1000 psi.

- **<u>Test 1161</u>:** Cell O6, Test 1; Felt Density 2051, Programmer: 1 in./ plate/ 1 in. Drop Height = 80 in., Peak G level = 402.06, Integrated Velocity Change = 35.5 ft/s, Measured Velocity Change = 21.08 ft/s, TTP Acceleration = 3.4 ms, TTP Velocity = 11.2 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator. Base pressure increased back to 1800 psi.

- **<u>Test 1162</u>:** Cell O6, Test 2; Felt Density 2051, Programmer: 1 in./ plate/ 1 in. Drop Height = 80 in., Peak G level = 420.17, Integrated Velocity Change = 35.54 ft/s, Measured Velocity Change = 21.17 ft/s, TTP Acceleration = 3.4 ms, TTP Velocity = 11.1 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator. Base pressure increased back to 1800 psi.

- **<u>Test 1163</u>:** Cell O6, Test 3; Felt Density 2051, Programmer: 1 in./ plate/ 1 in. Drop Height = 80 in., Peak G level = 429.74, Integrated Velocity Change = 35.9 ft/s, Measured Velocity Change = 24.78 ft/s, TTP Acceleration = 3.5 ms, TTP Velocity = 11.2 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator. Base pressure increased back to 1800 psi.

- **<u>Test 1164</u>:** Cell O6, Test 4; Felt Density 2051, Programmer: 1 in./ plate/ 1 in. Drop Height = 80 in., Peak G level = 447.5, Integrated Velocity Change = 36.41 ft/s, Measured Velocity Change = 19.81 ft/s, TTP Acceleration = 3.3 ms, TTP Velocity = 11.1 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator. Base pressure increased back to 1800 psi.

- **<u>Test 1165</u>:** Cell O6, Test 5; Felt Density 2051, Programmer: 1 in./ plate/ 1 in. Drop Height = 80 in.
  No Test - No data was recorded or produced for this test.

- **<u>Test 1166</u>:** Cell O6, Test 6; Felt Density 2051, Programmer: 1 in./ plate/ 1 in. Drop Height = 80 in., Peak G level = 450.98, Integrated Velocity Change = 36.35 ft/s, Measured Velocity Change = 21.54 ft/s, TTP Acceleration = 3.4 ms, TTP Velocity = 11.1 ms.
  Successful Test – All electronic data channels were present and continuous, data was successfully collected, desired test condition was achieved with addition of bungee accelerator. Base pressure increased back to 1800 psi.

APPENDIX E: SAMPLE DATA SHEETS – FELT PROGRAMMERS

Test 1126: Cell E, Felt Density 2051 (1.0 in.); Drop Height = 20 in., Peak G level = 184.94, Integrated Velocity Change = 17.04 ft/s, Measured Velocity Change = 10.15 ft/s, TTP Acceleration = 2.8 ms, TTP Velocity = 10.6 ms.

Test 1142: Cell K, Felt Density 2051 (1.0 in.); Drop Height = 80 in., Peak G level = 810.08, Integrated Velocity Change = 36.32 ft/s, Measured Velocity Change = 18.22 ft/s, TTP Acceleration = 1.9 ms, TTP Velocity = 9.4 ms.

Test 1152: Cell O1, Felt Density 2051 (0.5 in.); Drop Height = 20 in., Peak G level = 275.61, Integrated Velocity Change = 15.68 ft/s, Measured Velocity Change = 9.97 ft/s, TTP Acceleration = 1.8 ms, TTP Velocity = 9.4 ms.

Test 1156: Cell O3, Felt Density 2051 (0.5 in.); Drop Height = 80 in., Peak G level = 1245.64, Integrated Velocity Change = 33.42 ft/s, Measured Velocity Change = 18.12 ft/s, TTP Acceleration = 1 ms, TTP Velocity = 8.6 ms.

201306 Test: 1126 Test Date: 130607 Subj: 2051S1 Wt: .0
Nom G: 175.0 Cell: E

Data ID	Immediate Preimpact	Maximum Value	Minimum Value	Time Of Maximum	Time Of Minimum
Reference Mark Time (Ms)				0.1	
Drop Height (In)		20.00			
Impact Rise Time (Ms)				2.8	
Impact Duration (Ms)				6.4	
Velocity Change (Ft/Sec)		10.15			
CARRIAGE X ACCEL (G)	0.01	5.74	-5.56	3.8	1.1
CARRIAGE Y ACCEL (G)	0.02	4.05	-2.05	3.5	5.0
CARRIAGE Z ACCEL (G)	-0.92	184.94	-4.43	2.8	6.4
CARRIAGE RES ACCEL (G)	0.93	184.96	0.36	2.8	7.3
INTEGRATED ACCEL (FT/SEC)	9.58	10.15	-6.89	1.6	10.6
CARRIAGE X1 ACCEL (G)	0.10	2.78	-26.60	25.0	2.9
CARRIAGE Y1 ACCEL (G)	0.11	1.21	-26.77	9.8	3.2
CARRIAGE Z1 ACCEL (G)	-0.85	186.41	-6.73	2.7	8.6
CARRIAGE RES1 ACCEL (G)	0.87	189.08	0.22	2.7	12.4
CARRIAGE X2 ACCEL (G)	0.09	2.36	-16.65	25.5	2.8
CARRIAGE Y2 ACCEL (G)	-0.01	2.02	-11.25	5.3	3.3
CARRIAGE Z2 ACCEL (G)	-1.01	189.69	-4.59	2.8	7.2
CARRIAGE RES2 ACCEL (G)	1.01	190.48	0.30	2.8	40.3
TOP LEFT RETRACTION FORCE (LE	-11.55	277.77	-111.25	28.4	14.4
TOP RIGHT RETRACTION FORCE (	-3.23	565.84	-69.66	35.0	13.4

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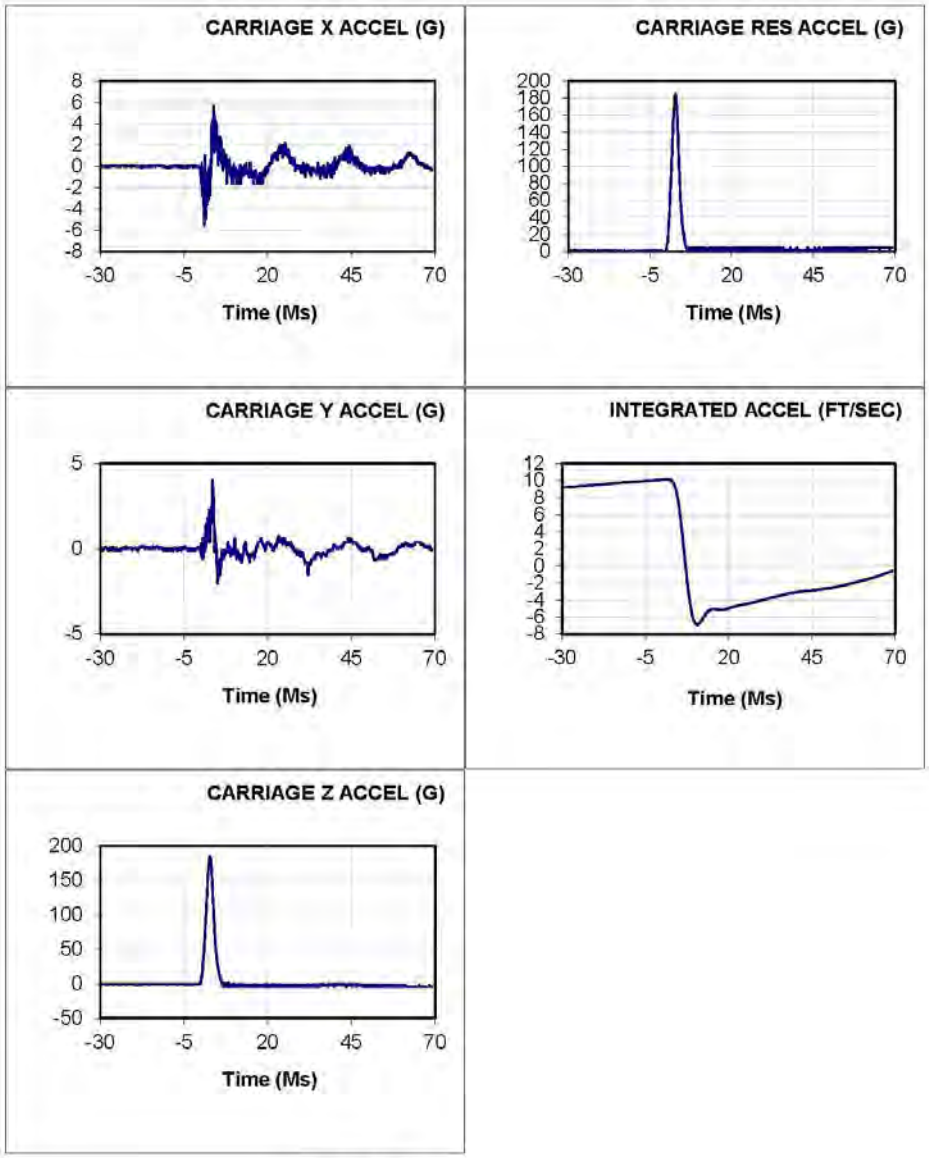
201306 Test: 1126 Test Date: 130607 Subj: 2051S1 Cell: E



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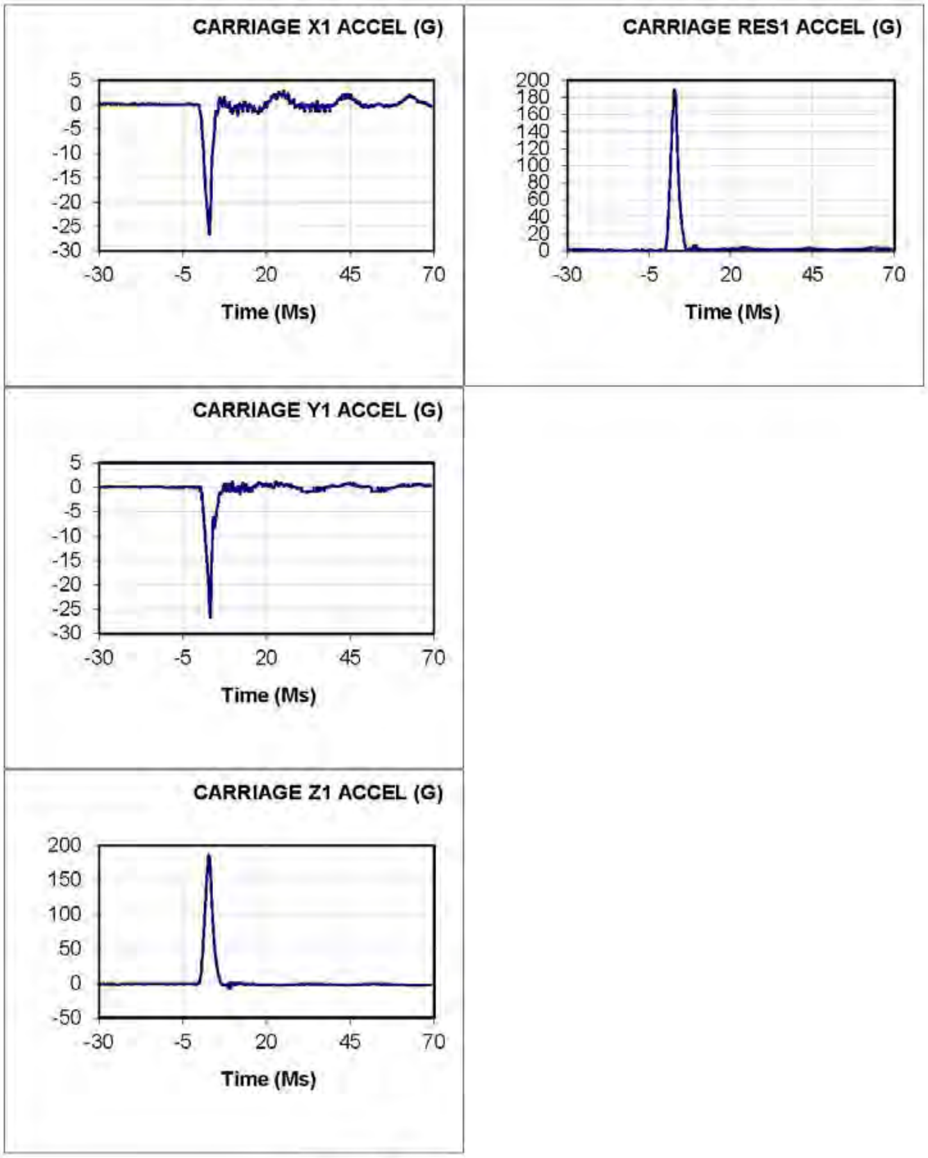
201306 Test: 1126 Test Date: 130607 Subj: 2051S1 Cell: E



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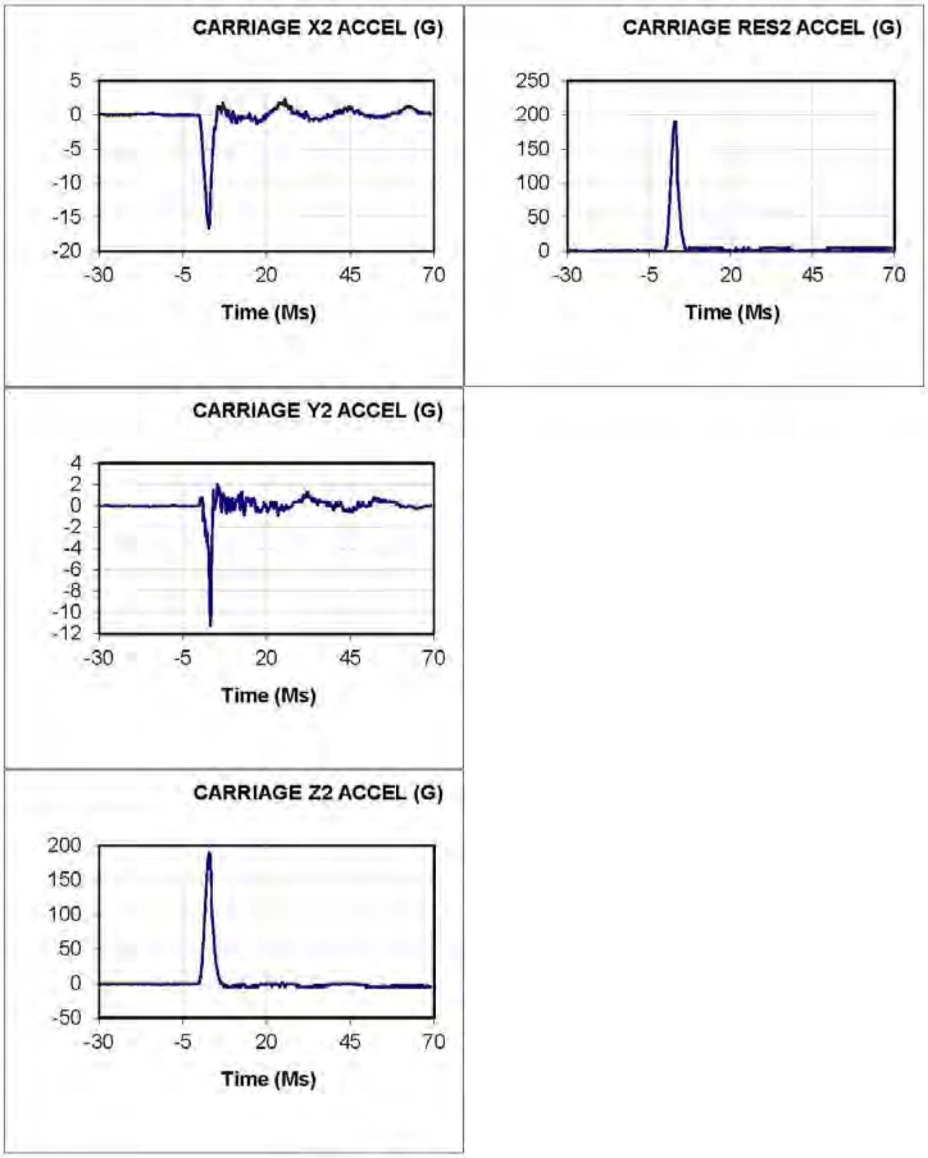
201306 Test: 1126 Test Date: 130607 Subj: 2051S1 Cell: E



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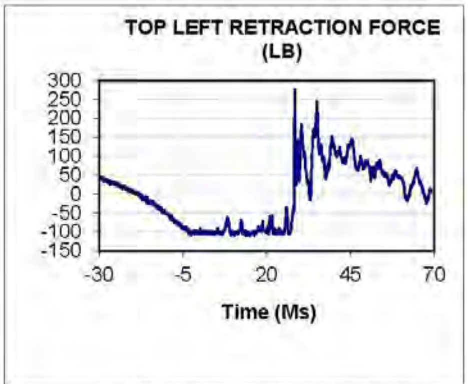
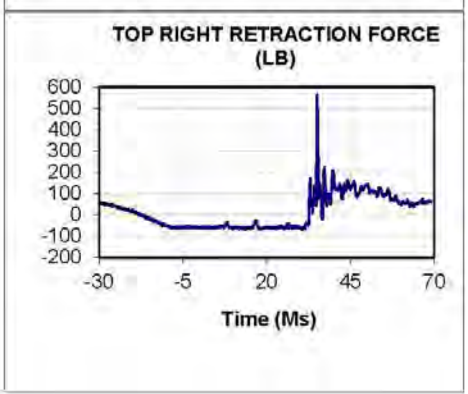
201306 Test: 1126 Test Date: 130607 Subj: 2051S1 Cell: E





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201306 Test: 1142 Test Date: 130621 Subj: 2051S1 Wt: .0
Nom G: 750.0 Cell: K

Data ID	Immediate Preimpact	Maximum Value	Minimum Value	Time Of Maximum	Time Of Minimum
Reference Mark Time (Ms)				0.1	
Drop Height (In)		60.00			
Impact Rise Time (Ms)				1.9	
Impact Duration (Ms)				3.4	
Velocity Change (Ft/Sec)		18.22			
CARRIAGE X ACCEL (G)	0.00	33.43	-22.22	2.7	1.5
CARRIAGE Y ACCEL (G)	-0.02	10.96	-14.34	4.3	3.0
CARRIAGE Z ACCEL (G)	-1.17	810.08	-34.46	1.9	9.4
CARRIAGE RES ACCEL (G)	1.17	810.15	0.13	1.9	28.9
INTEGRATED ACCEL (FT/SEC)	17.53	18.10	-18.22	1.2	9.4
CARRIAGE X1 ACCEL (G)	0.10	11.67	-107.89	4.8	1.9
CARRIAGE Y1 ACCEL (G)	0.07	56.31	-148.52	3.0	2.3
CARRIAGE Z1 ACCEL (G)	-1.28	784.87	-27.22	2.0	4.9
CARRIAGE RES1 ACCEL (G)	1.29	797.97	0.07	2.0	50.3
CARRIAGE X2 ACCEL (G)	0.07	14.03	-71.42	4.3	1.9
CARRIAGE Y2 ACCEL (G)	-0.09	39.16	-81.89	3.0	2.3
CARRIAGE Z2 ACCEL (G)	-1.01	824.06	-31.80	1.9	4.2
CARRIAGE RES2 ACCEL (G)	1.02	827.33	0.23	1.9	39.3
TOP LEFT RETRACTION FORCE (LI	6.20	2217.56	-104.55	38.1	14.3
TOP RIGHT RETRACTION FORCE (	36.39	2361.43	-157.76	45.3	34.2

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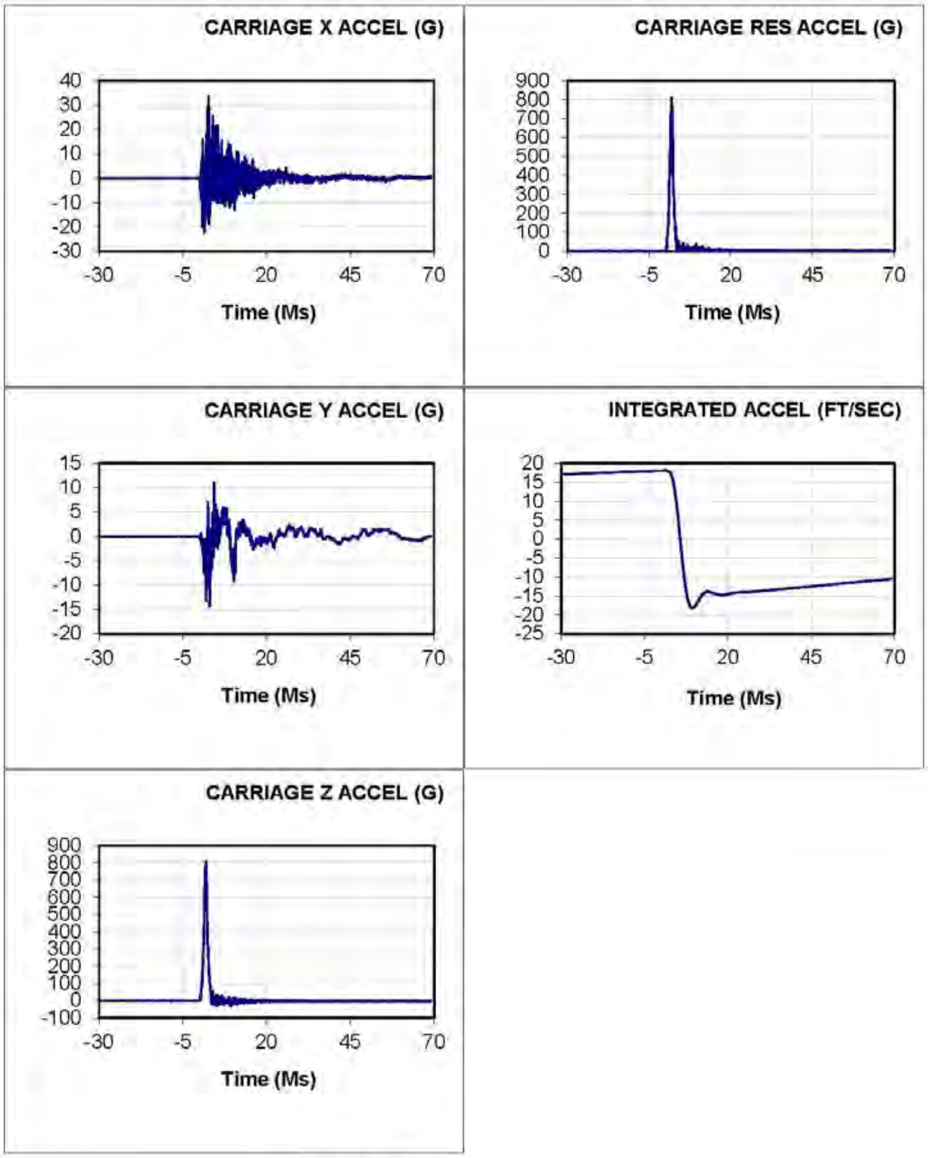
201306 Test: 1142 Test Date: 130621 Subj: 2051S1 Cell: K



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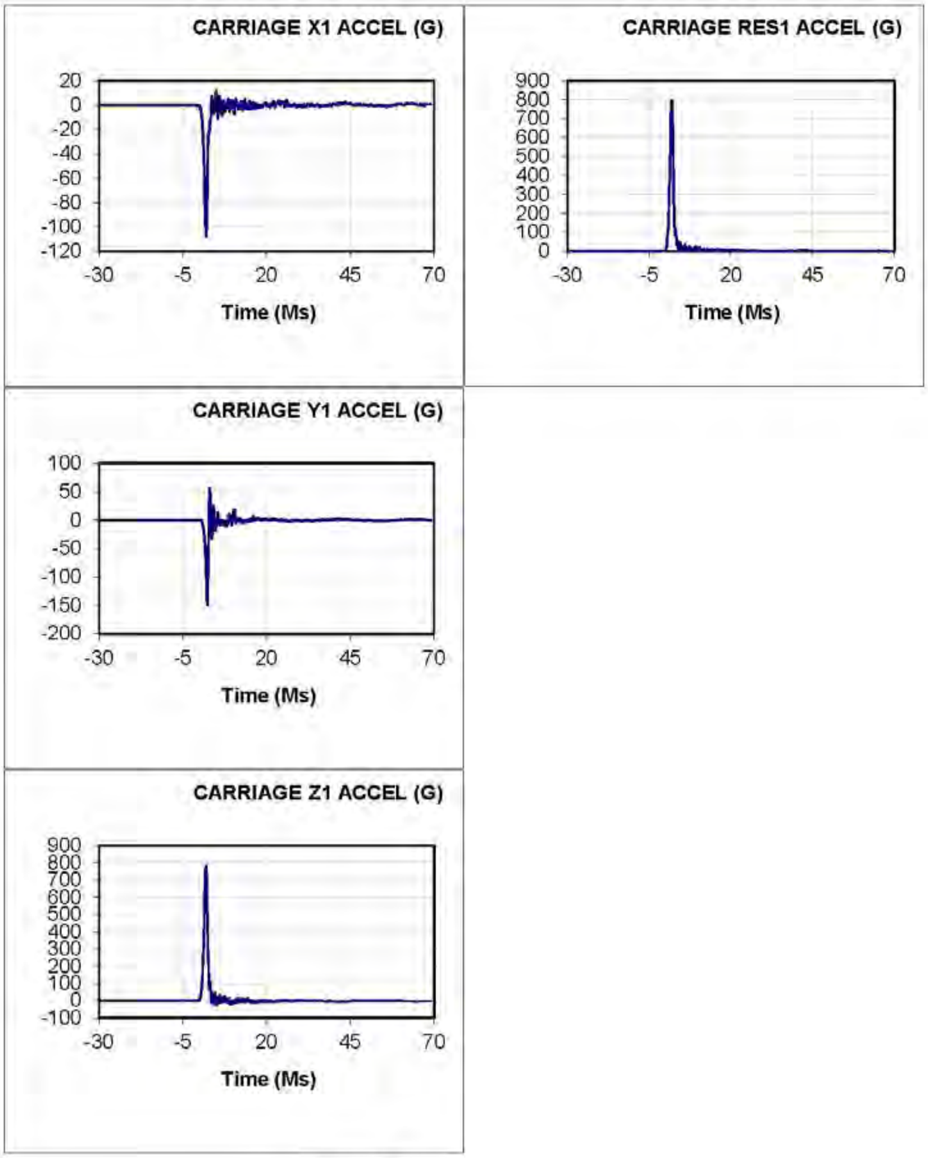
201306 Test: 1142 Test Date: 130621 Subj: 2051S1 Cell: K



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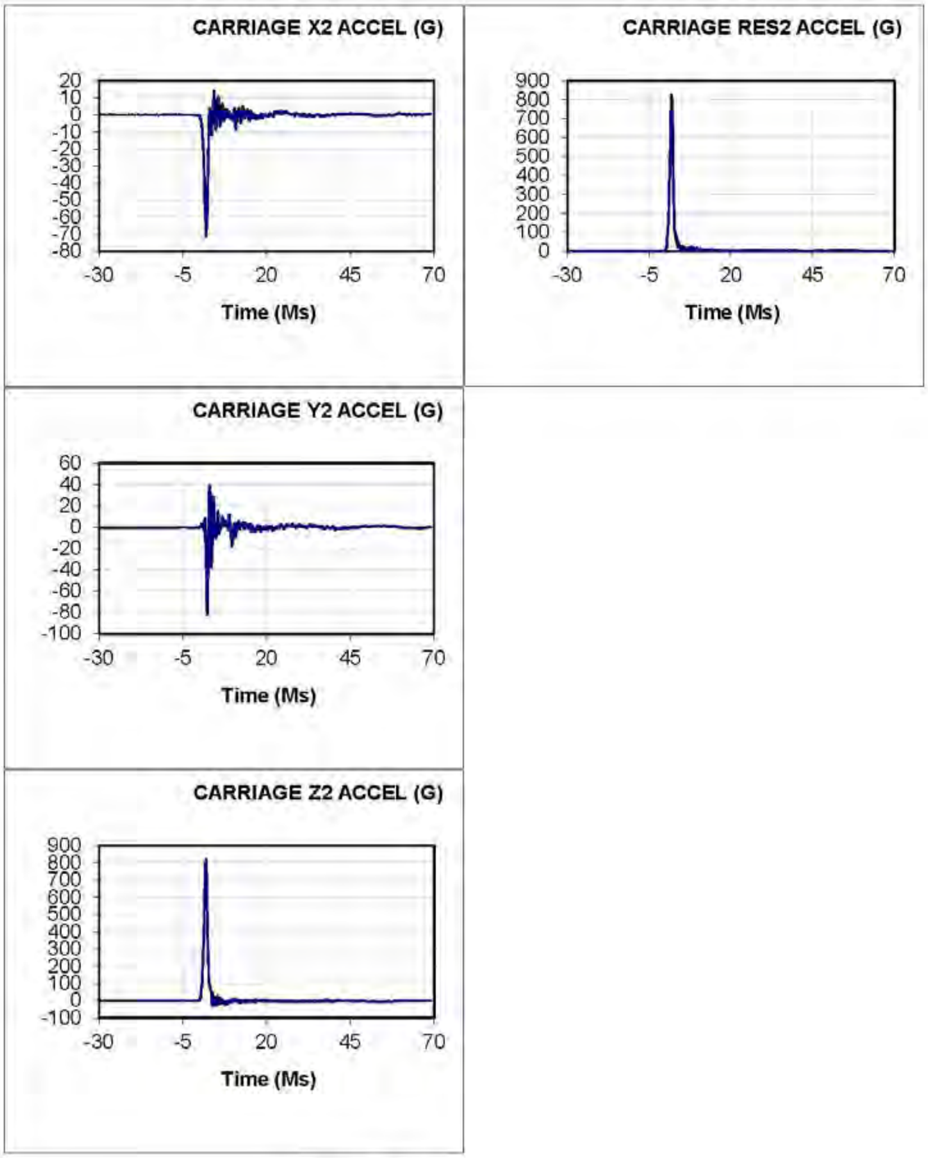
201306 Test: 1142 Test Date: 130621 Subj: 2051S1 Cell: K



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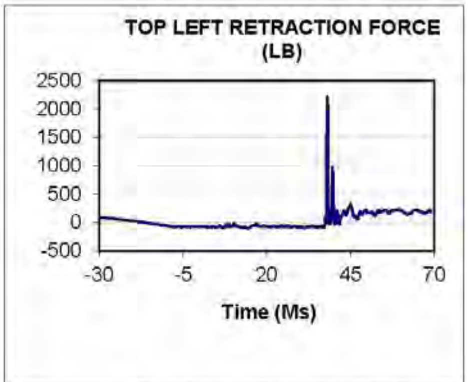
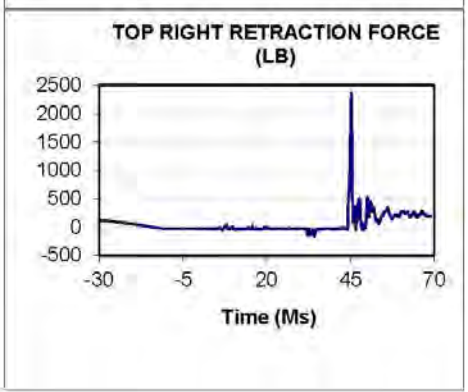
201306 Test: 1142 Test Date: 130621 Subj: 2051S1 Cell: K





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201306 Test: 1152 Test Date: 130717 Subj: 2051S150 Wt: .0
Nom G: 275.0 Cell: O1

Data ID	Immediate Preimpact	Maximum Value	Minimum Value	Time Of Maximum	Time Of Minimum
Reference Mark Time (Ms)				0.1	
Drop Height (In)		20.00			
Impact Rise Time (Ms)				1.8	
Impact Duration (Ms)				4.7	
Velocity Change (Ft/Sec)		9.97			
Offboard Velocity (m/sec)		2.96			
Offboard Velocity (Ft/Sec)		9.71			
CARRIAGE X ACCEL (G)	0.01	13.06	-17.03	2.5	1.5
CARRIAGE Y ACCEL (G)	0.00	3.79	-9.43	5.5	2.3
CARRIAGE Z ACCEL (G)	-0.69	275.61	-8.65	1.8	6.8
CARRIAGE RES ACCEL (G)	0.69	275.86	0.20	1.8	27.9
INTEGRATED ACCEL (FT/SEC)	9.57	9.97	-5.71	1.4	9.4
CARRIAGE X1 ACCEL (G)	0.10	7.40	-45.30	3.9	1.7
CARRIAGE Y1 ACCEL (G)	0.06	3.90	-40.90	8.1	2.1
CARRIAGE Z1 ACCEL (G)	-0.65	276.39	-10.83	1.7	7.6
CARRIAGE RES1 ACCEL (G)	0.67	281.99	0.37	1.7	18.4
CARRIAGE X2 ACCEL (G)	0.09	4.69	-34.03	4.1	1.6
CARRIAGE Y2 ACCEL (G)	0.00	8.92	-24.26	3.0	2.2
CARRIAGE Z2 ACCEL (G)	-0.62	283.37	-7.43	1.9	5.4
CARRIAGE RES2 ACCEL (G)	0.64	285.47	0.08	1.9	39.2
TOP LEFT FORCE (LB)	-55.24	176.89	-107.32	40.2	14.7
TOP RIGHT RETRACTION FORCE (	-24.59	332.71	-46.78	52.2	8.9

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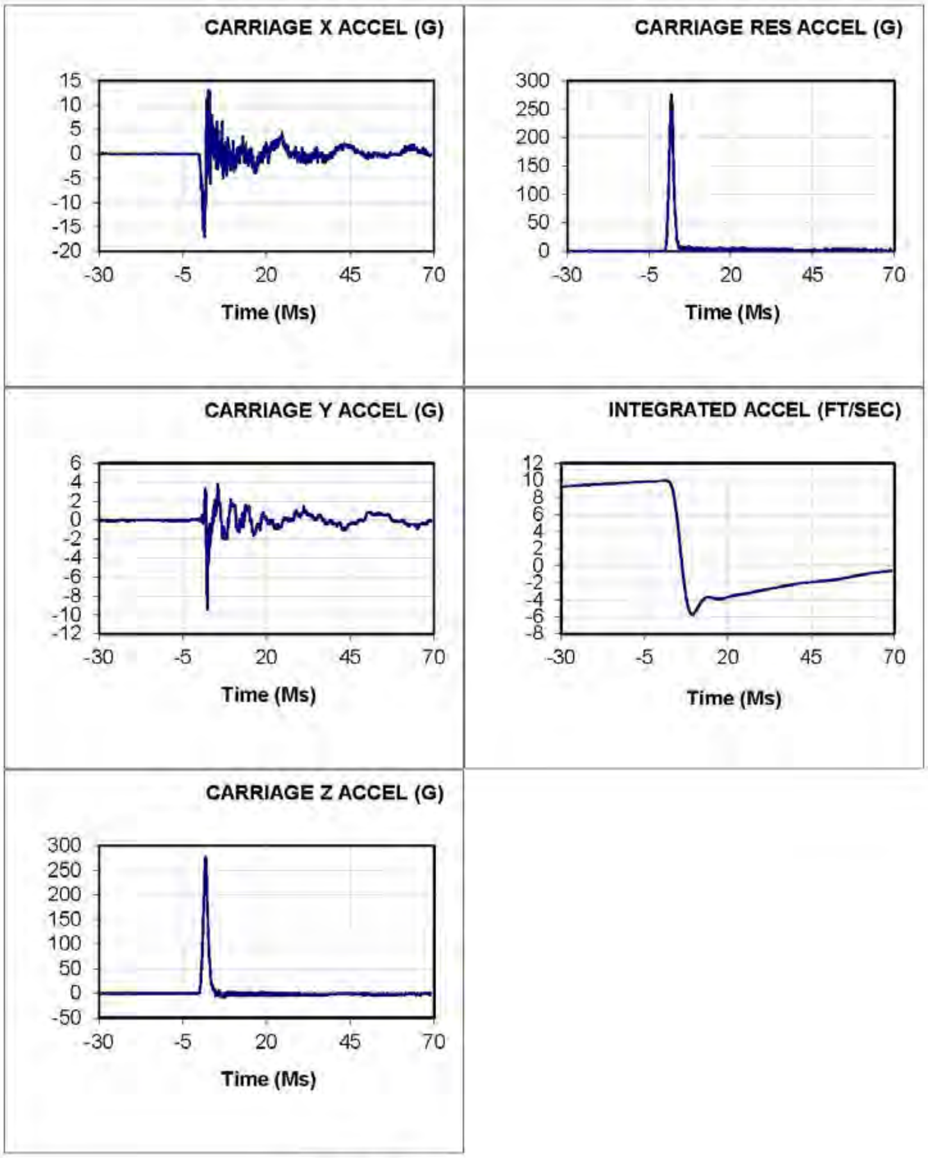
201306 Test: 1152 Test Date: 130717 Subj: 2051S150 Cell: O1



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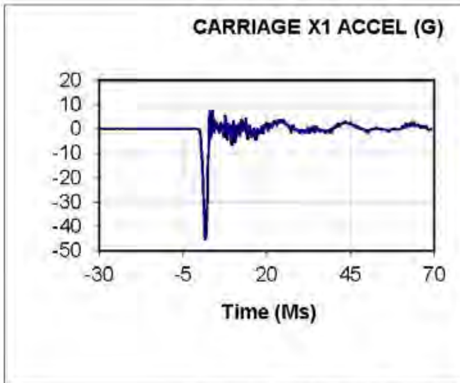
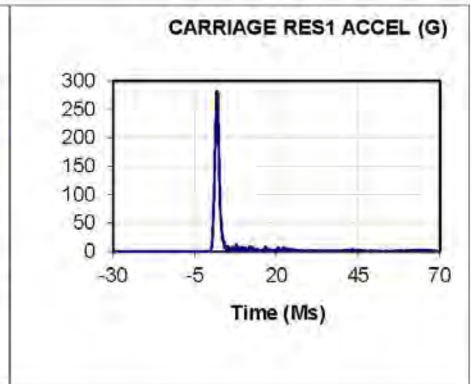
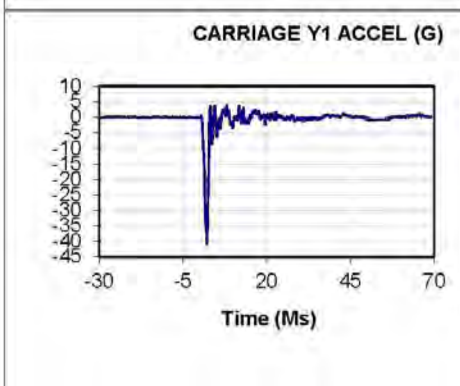
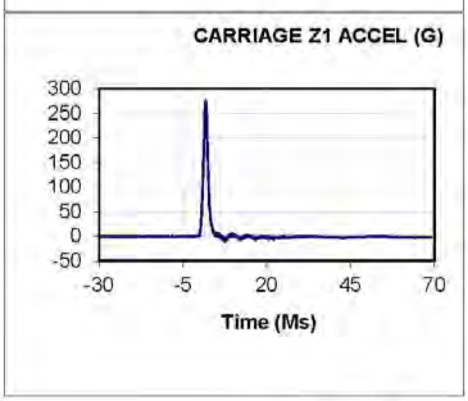
201306 Test: 1152 Test Date: 130717 Subj: 2051S150 Cell: O1

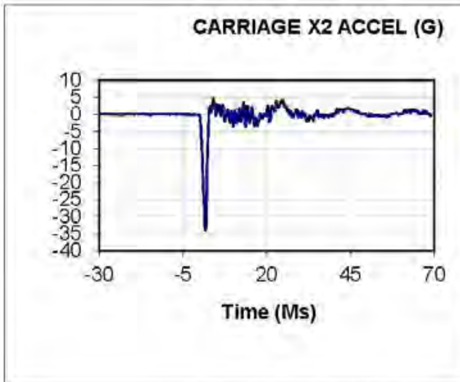


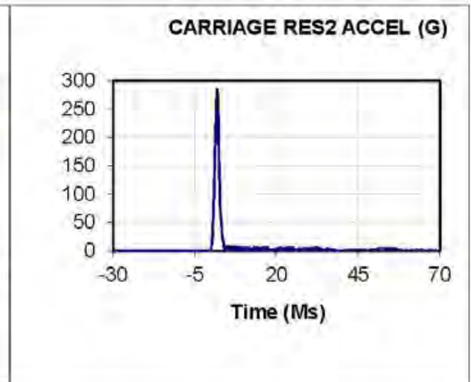


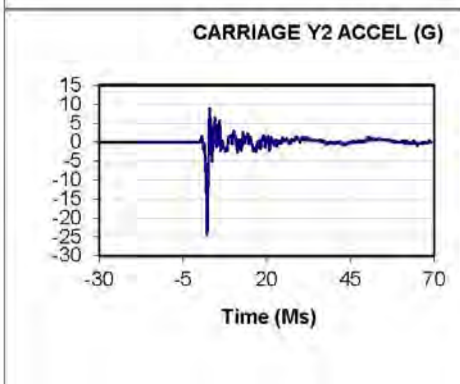


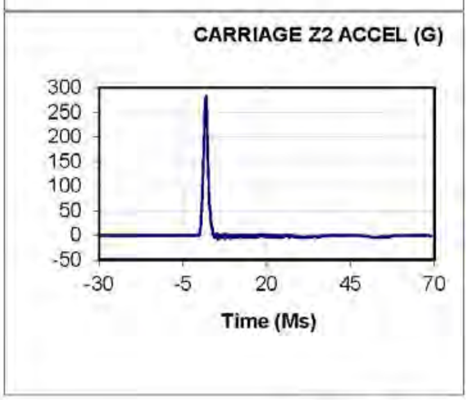


201306 Test: 1152 Test Date: 130717 Subj: 2051S150 Cell: O1









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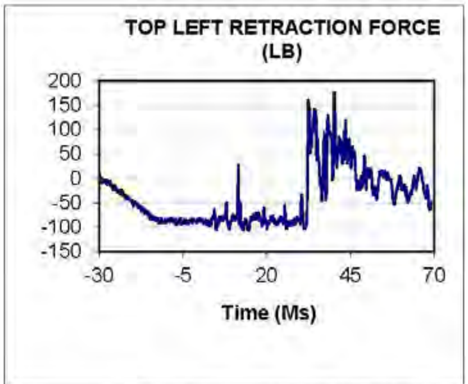
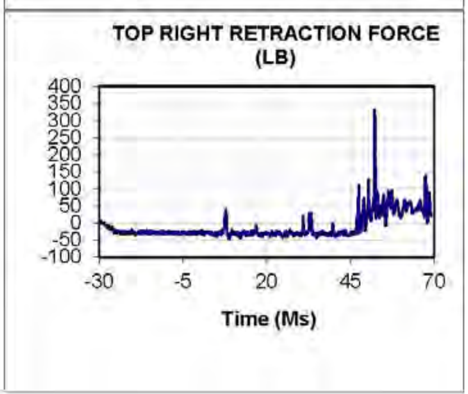
201306 Test: 1152 Test Date: 130717 Subj: 2051S150 Cell: O1





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201306 Test: 1156 Test Date: 130717 Subj: 2051S150 Wt: .0
Nom G: 900.0 Cell: O3

Data ID	Immediate Preimpact	Maximum Value	Minimum Value	Time Of Maximum	Time Of Minimum
Reference Mark Time (Ms)				0.1	
Drop Height (In)		80.00			
Impact Rise Time (Ms)				1.0	
Impact Duration (Ms)				2.6	
Velocity Change (Ft/Sec)		18.12			
Offboard Velocity (m/sec)		7.21			
Offboard Velocity (Ft/Sec)		23.65			
CARRIAGE X ACCEL (G)	0.01	80.86	-99.69	1.3	0.9
CARRIAGE Y ACCEL (G)	0.02	22.56	-32.86	2.3	1.6
CARRIAGE Z ACCEL (G)	-0.95	1245.64	-325.35	1.0	2.8
CARRIAGE RES ACCEL (G)	0.96	1247.28	0.29	1.0	34.3
INTEGRATED ACCEL (FT/SEC)	17.62	18.12	-15.30	1.0	8.6
CARRIAGE X1 ACCEL (G)	0.08	34.07	-224.96	1.7	1.2
CARRIAGE Y1 ACCEL (G)	0.11	186.03	-262.86	2.2	1.5
CARRIAGE Z1 ACCEL (G)	-1.06	1249.55	-144.46	1.0	2.0
CARRIAGE RES1 ACCEL (G)	1.07	1273.99	0.11	1.3	30.2
CARRIAGE X2 ACCEL (G)	0.08	32.65	-164.85	2.3	1.1
CARRIAGE Y2 ACCEL (G)	0.38	129.05	-127.29	2.1	1.4
CARRIAGE Z2 ACCEL (G)	-0.99	1280.12	3.52	1.9	0.0
CARRIAGE RES2 ACCEL (G)	1.07	1288.02	3.55	1.0	0.0
TOP LEFT FORCE (LB)	-22.51	1546.94	-126.05	40.0	4.3
TOP RIGHT RETRACTION FORCE (	2.84	2480.50	-328.51	47.3	38.7

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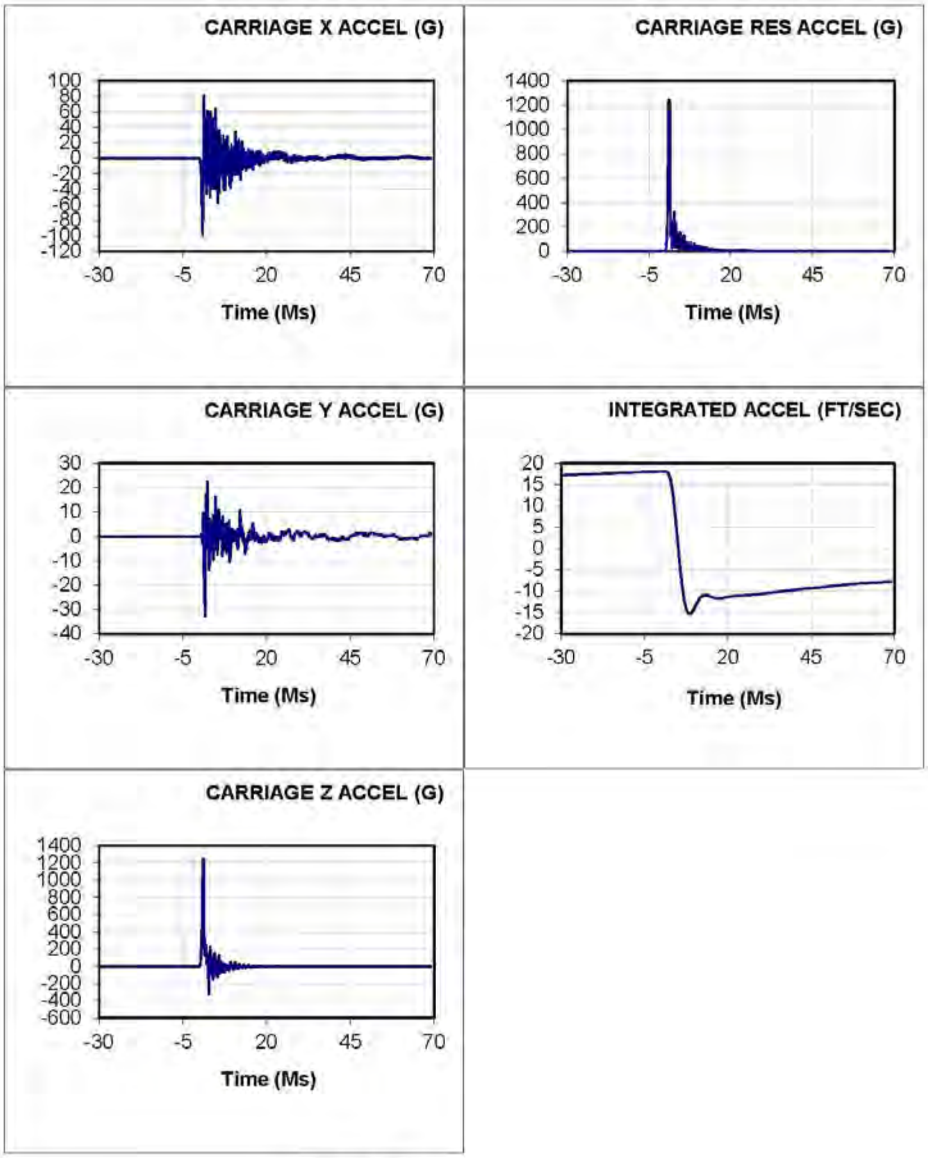
201306 Test: 1156 Test Date: 130717 Subj: 2051S150 Cell: O3



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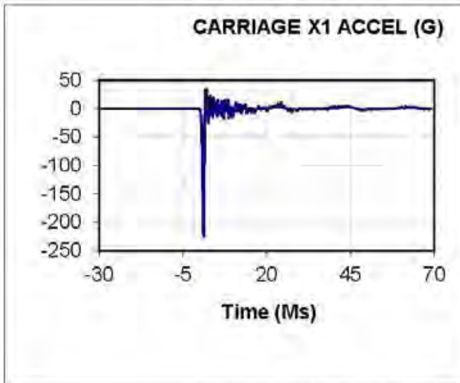
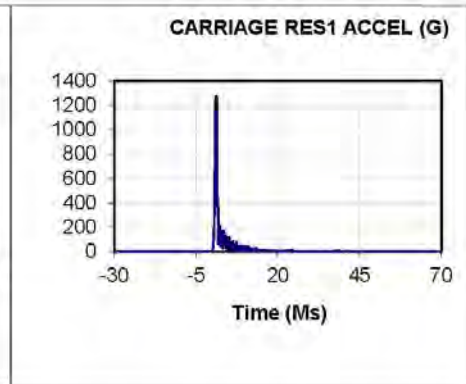
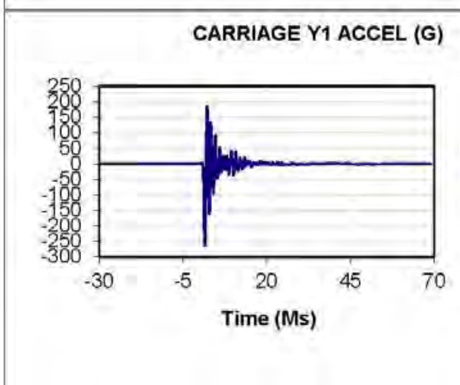
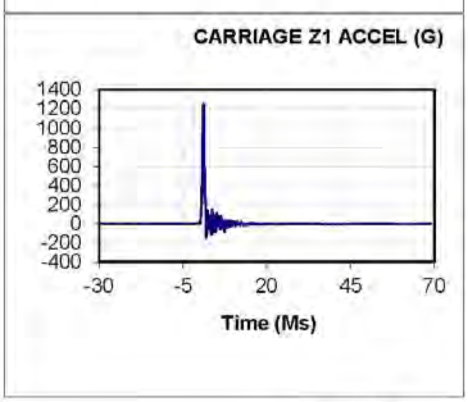
201306 Test: 1156 Test Date: 130717 Subj: 2051S150 Cell: O3









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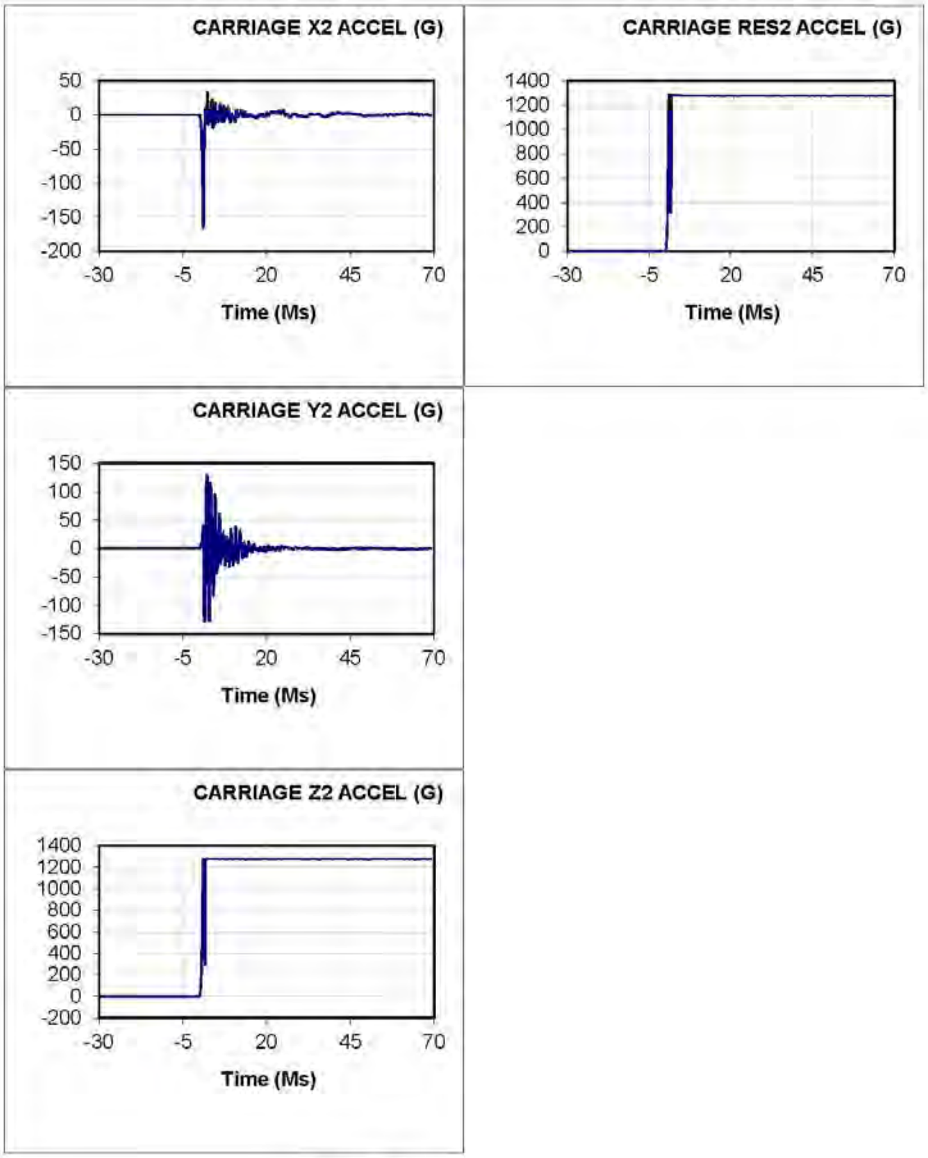
201306 Test: 1156 Test Date: 130717 Subj: 2051S150 Cell: O3



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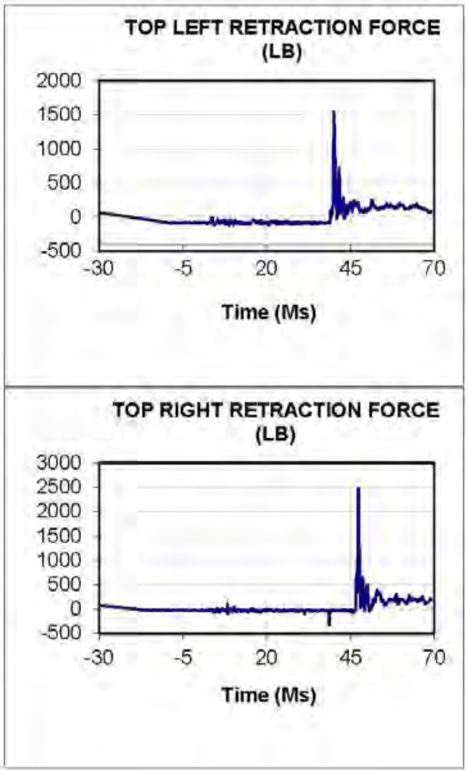
201306 Test: 1156 Test Date: 130717 Subj: 2051S150 Cell: O3



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